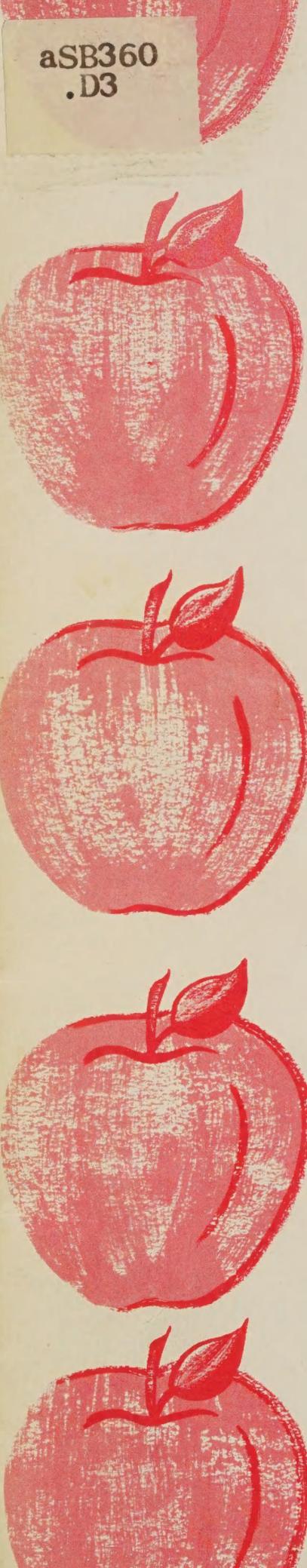


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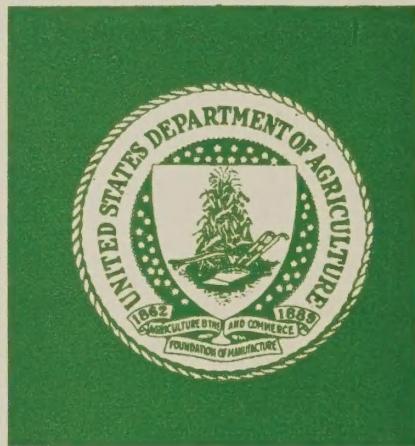
The Development of Controlled Atmosphere Storage of Fruit

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FOREWORD

This bulletin has been prepared as a reference work for Extension and research personnel. It may also be of broader interest.

The report should be considered as only an introduction to the development of controlled atmosphere (CA) storage of fruit. Emphasis is placed on stationary storage, primarily of apples. Full treatment, particularly of technical aspects, would require a book.

Mention of company or trade names is for identification purposes only and is not to be interpreted as endorsement by the Department of Agriculture.

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THE DEVELOPMENT OF CONTROLLED ATMOSPHERE
STORAGE OF FRUIT

by Dana G. Dalrymple*

I. INTRODUCTION

The use of controlled atmospheres bids fair to become the most important innovation in the preservation of horticultural produce since the introduction of mechanical refrigeration. Prior to 1940, controlled atmosphere (CA) storage was commercially unknown in the U. S.; by the fall of 1965, nearly 13 million bushels of apples were held in CA storage. Studies are underway on the application of CA to other fruits and vegetables. And new developments are being used to extend CA to transportation and distribution refrigeration units.

The controlled atmosphere process, as it is generally used, involves refrigeration and the regulation of the oxygen and/or carbon dioxide levels in the atmosphere in order to retard the ripening and deterioration of fruit. Harvested fruit, like humans, respires; it uses up oxygen and carbohydrates and gives off carbon dioxide, water, and heat. The faster the respiration, the faster the fruit ripens. Normally, respiration is significantly retarded by refrigeration. But it can be further slowed by lowering the oxygen level of the atmosphere and/or increasing carbon dioxide to specified levels in an air-tight room.^{1/} The result is slower ripening, and extended storage and shelf life.^{2/} The combination of refrigeration and atmosphere regulation means that the consumer can have higher quality produce later in the season than is possible with refrigeration alone.

Although CA (controlled atmosphere) storage is a relatively new process in the eyes of many, it has a long, involved, and international history. The

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^{1/} Air usually contains 78% nitrogen, 20.8% oxygen, and 0.03% carbon dioxide. The exact atmosphere content in CA storage varies sharply with the type or variety of fruit, type of CA process, etc., but in the case of apples generally involves levels of less than 5% oxygen, and 1 to 7% carbon dioxide, with the balance made up of nitrogen.

^{2/} In the case of apples: (a) the low oxygen level retards softening, quality changes, breakdown, and scald development; (b) the high carbon dioxide level retards the normal ground color change and the development of decay, scald, and Jonathan spot (based on the reports by Smock cited in footnote 3, p. 2).

development of CA illustrates, possibly to a unique degree, the successful transmission of a scientific concept from laboratory to large-scale commercial use. Moreover, CA is a clear-cut example of a process which was developed in the public sector and ultimately adopted and enlarged by private industrial firms. Finally, the development of CA led to the happy situation where both the major parties involved are better off: the farmer is able to benefit from an extended selling season and generally better prices, and the consumer is able to purchase a product of high quality over a longer period of time.

In view of these factors, this report will attempt to outline the development of controlled atmosphere storage from its inception through 1966. Although much has been written about CA storage, it is nearly always of a relatively narrow technical nature. This bulletin seeks to provide a broader historical perspective; where possible, it brings in economic and social considerations. As most of the experience to date -- both scientific and commercial -- has been with the storage of apples, this area will receive particular attention.^{3/} Hopefully, this approach will not only provide the technical specialist wider scope and background, but it will also supply the more general reader with a case study of successful technical innovation.

^{3/} References to technical works will be found in the footnotes. Readers desiring a general technical introduction may wish to consult R. M. Smock: Controlled Atmosphere Storage of Apples, Cornell University, Extension Bulletin 759, May 1958, 35 pp.; "Recent Advances in the Controlled Atmosphere Storage of Fruits," HortScience, Winter 1966 (Vol. 1, No. 1), pp. 13-15.

II. EARLY WORK

In some form, controlled atmosphere storage has been more or less accidentally carried out for many years. The old custom of burying barrels of apples in the ground and covering them with soil and trash ~~was~~ probably a crude form of CA storage. The ~~same~~ is true for the early transport of fruit in unventilated holds of ships.^{1/} But if the fruit stored well, it ~~was~~ an accident; the reasons were not known. Nor could poor results be explained. There ~~was~~ no scientific basis of knowledge. In this chapter we will review some of the early scientific work on or with controlled atmospheres. We will cover the 100-year period from the early 1800's through the early 1900's.

A. French Study

The first scientific investigation of the effect of atmospheres on fruit ripening appears to have been conducted by Jacques Etienne Berard. Berard was a professor at the School of Pharmacy at Montpellier and a "correspondant" of the French Academy of Sciences. The results of his studies, which were conducted in 1819 and 1820, were published in 1821 and earned the "Grand Prix de Physique" from the Academy.^{2/}

As part of a more general study, Berard recognized that harvested fruits utilize oxygen and give off carbon dioxide. He stated that fruits placed in an atmosphere deprived of oxygen do not ripen. But he added that this ability is only suspended if the fruit has not been held too long; the ripening process can be reactivated by putting the fruit in regular air. Consequently, Berard suggested that it ~~was~~ possible to preserve the fruits for some time, and thus "prolong the enjoyment" derived from them.

The procedure Berard used was to place an absorbent chemical "paste" in a jar and then insert sound fruits picked before maturity (isolating the

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- 1/ The matter of hold ventilation is discussed in ~~some~~ detail by Franklin Kidd, Cyril West, and N. A. Kidd in Gas Storage of Fruit, Department of Scientific and Industrial Research (U.K.), Food Investigation Special Report No. 30, 1927, Chapter 10, especially p. 47.
- 2/ Jacques Etienne Berard, "Mémoire sur la Maturation des Fruits," Annales de Chimie et de Physique, 1821 (Vol. 16), pp. 152-183, 225-251, especially pp. 178, 248-250. Berard had a distinguished career: he ~~was~~ named to the Faculty of Medicine at Montpellier in 1832 and was elected Dean in 1846. From 1837 to 1839 he served as Deputy from Herault. An "intime" of many of the leading scientific figures of his day, he was also a member of the famous "Société d'Arcueil." (These and other biographical details were kindly provided by R. Courrier of the Académie des Sciences, Paris, in a letter dated October 21, 1966.)

fruits physically from the chemicals as much as possible).^{3/} The jar was then sealed and, according to Berard, the fruit was soon in an atmosphere deprived of oxygen. He indicated that fruit could in this way be kept, apparently at room temperature, as follows: peaches, prunes, and apricots, from twenty days to a month; pears and apples, about three months. Fruit taken out after this period would ripen normally; that held longer would not.

Although Berard's study attracted scientific attention, it does not seem to have received any commercial application.^{4/}

B. Cleveland Storage

Quite independently of Berard, a remarkable Cleveland storage operator, Benjamin Nyce, built and operated a storage in the late 1860's which utilized many of the essential components of controlled atmosphere storage.

Nyce recognized the basic chemistry of the fruit ripening or respiration process. He explained it this way:

In a room or any confined vessel, when filled with fruit in the gradual process of ripening, carbonic acid and water are constantly generated The oxygen ... will usually be consumed in about forty-eight hours. The atmosphere is then made up of the nitrogen of the air and carbonic acid. The former is destituted of all active properties, good or bad. The latter is not found to have any action on fruit immersed in it. Hydrogen and carbon then cease to be evolved from the fruit as there is now no agent to unite with them Decomposition ceases.^{5/}

-
- 3/ The "paste" was composed of lime, iron sulfate, and water. While these chemicals react to absorb oxygen, they would also absorb carbon dioxide; lime, in fact, is now used by itself to remove excess carbon dioxide in many commercial apple storages. The result may have been both low oxygen and low carbon dioxide levels -- what is now known as a "low oxygen" atmosphere. (The reactions of Berard's "paste" have been discussed with Dr. Rolf B. Johannessen, Inorganic Chemistry Section, National Bureau of Standards.)
 - 4/ See: W. D. Bigelow, et al., Studies on Apples, U. S. Department of Agriculture, Bureau of Chemistry, Bulletin 94, 1905, pp. 9-10 (based on a French summary).
 - 5/ "An Old Fruit House," Ice and Refrigeration (now Industrial Refrigeration), July 1895 (Vol. 9, No. 1), p. 23. (The article consists largely of quotes from a circular apparently written by Nyce between 1871 and 1873; he died in 1873.)

While Nyce clearly had the general concept, he did not seem to realize that the fruit could be injured by oxygen levels that are too low or carbon dioxide levels that are too high.

Nyce's storage -- which seems to have been constructed about 1865 -- was built to be air tight. It ~~was~~ lined with "air-tight casings, made of common sheet iron, No. 26, the edges thickly painted and nailed to upright studding."^{6/} The effectiveness of this procedure is testified to by the fact that when the chambers were filled with fruit, "they would soon become ~~so~~ charged with carbonic acid gas that a light would not burn in them."^{7/} The building itself ~~was~~ insulated and cooled by an unusual ice system. Nyce did not let the temperature rise above 34° F. He had a mistaken idea that it was necessary to keep the humidity as low as possible and worked out a way of measuring and controlling the moisture level (the latter involved the use of a form of calcium chloride).

Apparently the fruit generally came out in good condition. However, he did report problems which sound like carbon dioxide injury in some barrels later in the season. He found that this problem was reduced by opening the containers. One at first might wonder why he did not experience more carbon dioxide injury in view of his lack of controls. But this possibility may have been reduced by several factors: (1) the door, while tight, was apparently not sealed and if opened fairly often would let a certain amount of air in, and (2) there was probably some air leakage through the walls.

The storage ~~was~~ evidently profitable. Nyce reported the following figures for 4,000 bushels of apples stored during the 1870/71 season: cost, \$.60/bu.; selling price, \$2.40/bu. However, out of the 4,000 bushels, 300 were sold for vinegar, bringing in \$75 for the lot. Thus, the gross profit for the storage was around \$6,700. How typical this gross was is not known.

Despite a certain amount of publicity and apparently favorable results, no evidence ~~was~~ found that the system was used at all widely. Large sums were offered for the patent rights but Nyce apparently preferred to hold on to them. While the system was discussed in an article in the Yearbook of Agriculture for 1900, it ~~was~~ not mentioned in any other scientific literature reviewed.^{8/}

6/ John A. Warder, Apples (American Pomology), Orange Judd Co., New York, 1867, p. 291. (The book contains three drawings of Nyce's storage.)

7/ Thos. L. Rankin, "Prof. Benj. M. Nyce," Ice and Refrigeration, June 1894 (Vol. 6, No. 6), p. 405. (This article provides biographical information on Nyce.)

8/ William A. Taylor, "The Influence of Refrigeration on the Fruit Industry," Yearbook of Agriculture, 1900, U. S. Department of Agriculture, 1901, p. 565.

C. American Research

The third stage in the early work relating to controlled atmosphere storage took place in the early 1900's. It ~~was~~ composed of research done by State land grant college and U. S. Department of Agriculture personnel. However, the work on atmospheres was, with ~~one~~ exception, but part of a more general project aimed in ~~some~~ direction other than extending storage life.

The first American scientists to have noted the effect of different atmospheres on length of fruit life appear to have been R. W. Thatcher and N. O. Booth of Washington State University. Around 1903, they "undertook an investigation of the possibilities of slowing up the ripening of fruits by ~~means~~ other than cold storage."^{9/} One of the methods they tried ~~was~~ to seal apples in each of five different atmospheres: hydrogen, nitrogen, oxygen, carbon dioxide, and sulphur dioxide. An air check ~~was~~ provided. The apples were placed in jars which held about a peck, filled with the gas, and left in a warm, light laboratory. After six months the jars were opened.

The apples which had been in carbon dioxid [sic] were firm in flesh, possessed the characteristic apple color, although the gas in the jar had a slight odor of fermented apple juice, and ~~were~~ not noticeably injured in flavor.

The apples stored in other gases did not fare so well. The researchers observed, therefore, that "the phenomena ordinarily associated with ripening were greatly inhibited by an atmosphere of carbon dioxid." The experiment ~~was~~ repeated the following ~~year~~ using small fruit: raspberries, blackberries, and loganberries. In this case, "It was found that berries which softened in three days in air would remain firm for from 7 to 10 days in carbon dioxid." At this point, Booth left the University and the studies were -- unfortunately -- not continued.^{10/}

A few years later, in 1907, Fulton of the U. S. Department of Agriculture noted in a bulletin on strawberries that fruit ~~was~~ damaged "little, if any ... by the presence of a small amount of carbon dioxide in the air of the

9/ It is not possible to be precise about the exact date because the work ~~was~~ not reported until 1915 -- and then the reference ~~was~~ to "several years ago." However, the study ~~was~~ done while Booth ~~was~~ employed by the University. A check of records reveals that he ~~was~~ with the University from September 1902 to June 1904 (letter from Louis L. Madsen, Dean, College of Agriculture, Washington State University, September 14, 1966).

10/ R. W. Thatcher, "Enzymes of Apples and Their Relation to the Ripening Process," Journal of Agricultural Research, October 18, 1915 (Vol. 5, No. 3), pp. 103-105. Reasons for the delay for publication of these findings may be found on p. 103.

storage room." He added that "only in the presence of a large amount of this gas does real injury occur."11/

In 1913, George R. Hill reported in a Cornell University bulletin that "to some extent peaches can be prevented from softening by inert gases, and especially by carbon dioxid." He also observed that the rate of respiration did not return to normal after storage in a carbon dioxide atmosphere for a few days. Hill added that he planned to extend his work a following season to bring in the temperature variable, but does not seem to have done so.12/

Subsequently, several researchers noted the effect of carbon dioxide on storage life and respiration while studying apple scald. The first were Charles Brooks and J. S. Cooley of the U. S. Department of Agriculture. In one laboratory experiment, apples were placed in a container in which the air ~~was~~ renewed three times a week; the incoming air had 5% CO₂. They noted after five weeks that the fruit remained "green, firm, and crisp." They went on to state that:

The results indicated that storage for a short time in a atmosphere in which the carbon dioxid has been greatly increased and the oxygen correspondingly decreased causes apples to become slightly alcoholic and to take on a rigor or an inactive condition from which they do not entirely recover....13/

A similar observation was made by F. W. Allen, whom we will mention again later, in 1918 (though it was not reported until 1935). But in his case, the apples were in sealed cans and "became so alcoholic as to be worthless."14/

11/ S. H. Fulton, The Cold Storage of Small Fruits, U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin 108, September 1907, p. 17.

12/ G. R. Hill, Jr., Respiration of Fruits and Growing Plant Tissue in Certain Cases, With Reference to Ventilation and Fruit Storage, Cornell University, Agricultural Experiment Station, Bulletin 330, April 1913, p. 406. (This bulletin was based on his Ph.D. dissertation of the ~~same~~ title filed in 1912.) Also see his article, "The Relation of Ventilation to the Keeping Quality of Fruits and Vegetables," Washington University Studies, July 1913 (Vol. 1, No. 1), pp. 46-64 (Hill was listed as being on the staff of the Missouri Botanical Garden).

13/ Charles Brooks and J. S. Cooley, "Effect of Temperature, Aeration and Humidity on Jonathan-Spot and Scald of Apples in Storage," Journal of Agricultural Research, November 12, 1917 (Vol. 11, No. 7), pp. 306-307.

14/ F. W. Allen and L. R. McKinnon, "Storage of Yellow Newtown Apples in Chambers Supplied With Artificial Atmospheres," Proceedings of the American Society for Horticultural Science for 1934 (Vol. 32), 1935, p. 146.

A more general study of the storage of apples by Magness and Diehl, which was published in 1924, indicated that:

There was a marked relationship between CO_2 concentration and the rate of softening of the fruit. An atmosphere containing even 5 per cent CO_2 resulted in a distinctly slower rate of softening than did air of the normal concentration, while higher concentrations resulted in still further decreasing the softening rate.

It was found, however, that flavor was impaired when carbon dioxide exceeded 20%.^{15/}

* * *

Thus, we can see that the nature of the carbon dioxide-oxygen relationship and its influence on fruit ripening and storage had been noted by a number of scientists by the early 1920's. However, none of them pushed it very far, and none seemed to have studied the effects of concurrent temperature variations. Nyce put the basic ingredients of atmosphere and temperature together in a commercial operation, but did not face the critical question of the optimum carbon dioxide - oxygen balance.

But, in retrospect, the critical problem was that these observations and experiences were more or less independent events and generally remained unnoted or unused. No one at the time really added them up. They did not seem to have led to any further work on CA storage. They were, in a sense, prehistory. The real start of CA storage had to await the later work of two British scientists who started from quite a different vantage point.

15/ J. R. Magness and H. C. Diehl, "Physiological Studies on Apples in Storage," Journal of Agricultural Research, January 5, 1924 (Vol. 27, No. 7), pp. 33-34.

III. PERIOD OF INTENSIVE STUDY

Following a hundred-year period of sporadic activity, intensive scientific study got underway following World War I. In this section we will look at the work that was done in the interwar period up to World War II. The period is divided into three main phases: (A) the seminal studies of Kidd and West in England which started in 1918; (B) subsequent investigations in the United States which got underway in 1928; (C) and research in other nations, principally Canada, which started in 1933.

A. United Kingdom

The first truly intensive and systematic research on controlled atmosphere storage was initiated in England by Dr. Franklin Kidd and Dr. Cyril West. Both were associated with the Low Temperature Research Station at Cambridge, a unit of the Food Investigation Board of the United Kingdom's Department of Scientific and Industrial Research.

Kidd became involved in studying the influence of carbon dioxide on respiration while a fellow of St. John's College, Cambridge. His original work was on seeds and was published in January 1916.^{1/} Subsequently he became associated with a Food Investigation Board study at Cambridge on the low temperature physiology of plant foods which started by examining the influence of the composition of the surrounding atmosphere.^{2/}

In 1918, he and Cyril West initiated exploratory laboratory experiments on fruits at Cambridge. Various temperatures and atmospheres were used. Fruits involved were apples, pears, plums, strawberries, gooseberries, and raspberries.

It was found that, in general, the ripening of fruits in storage could be retarded without ill effect on their condition, by reducing the amount of oxygen in the air; it was also found that a certain amount of carbon dioxide in the air retarded ripening.^{3/}

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- 1/ Franklin Kidd, "The Controlling Influence of Carbon Dioxide. Part III. The Retarding Effect of Carbon Dioxide on Respiration," Proceedings of the Royal Society (London), Series B, January 1, 1916 (Vol. 89, No. B-612) pp. 136-156. (Parts I and II were published in 1914.)
- 2/ "Fruit and Vegetable Committee," Report of the Food Investigation Board, 1918 (Department of Scientific and Industrial Research), 1919, p. 11.
- 3/ Franklin Kidd, Cyril West, and N. A. Kidd, Gas Storage of Fruit, Department of Scientific and Industrial Research, Food Investigation Special Report No. 30, 1927, p. 4.

In the 1919 report of the Board, it was indicated that they were able to extend the storage life of strawberries to three or four weeks at 1° to 2°C if maintained "in atmospheres containing reduced amounts of oxygen and moderate amounts of carbon dioxide obtained by keeping the berries in a closed vessel fitted with an adjustable diffusion leak." Results on plums were reported to be similar. Tests were underway with a number of varieties of apples and pears.^{4/}

For the next few years their work centered on apples. The laboratory work had suggested that the ripening of apples could be retarded in atmospheres containing 10 to 15% carbon dioxide and 5 to 10% oxygen.^{5/} Therefore, during the 1919/20 season larger-scale tests were conducted at the "John Street Store" of the Port of London Authority. Storage life ~~was~~ roughly doubled in an atmosphere of 14% carbon dioxide and 8% oxygen.^{6/}

During the 1920/21 season, trials were initiated on a semi-commercial scale in a newly-erected storage. The storage ~~was~~ built by a Mr. John Chivers on one of his farms at Histon from a design prepared by Dr. Kidd. It did not have a cooling system. Provision ~~was~~ made for five chambers, each holding a ton. The Board's report for 1920, filed before the results were completed, suggested that the "gas" (the British term for controlled atmosphere) system made it possible approximately to double storage life of the varieties tested.^{7/} Thereafter, it was noted that "The apples were firm and green and showed no tendency to break down rapidly after being taken out of store." Samples were exhibited in May and June of 1921.^{8/}

During the 1921/22 season, the Histon storage was remodeled to provide a larger chamber of 8-10 tons.^{9/} That season's testing ~~was~~ also regarded as a success. In addition, "The average gross return obtained by sale after storage ~~was~~ 2.34 times the gross cost of the apples when received for

4/ "Fruit and Vegetable Committee," Report of the Food Investigation Board, 1919 (Department of Scientific and Industrial Research), 1920, pp. 17-19.

5/ Kidd, et al., op. cit., p. 5.

6/ "Fruit and Vegetable Committee," Report of the Food Investigation Board, 1920 (Department of Scientific and Industrial Research), 1921, pp. 16, 18. The term "1919/20" refers to the apple crop which ~~was~~ harvested in the fall of 1919 and sold through the early part of 1920.

7/ Ibid., pp. 18-19. Also ~~see~~ Kidd, et al., op. cit., p. 13. A diagram of the storage is presented in Plate IV of the reference cited in footnote 12.

8/ "Fruit and Vegetable Committee," Report of the Food Investigation Board, 1921 (Department of Scientific and Industrial Research), 1922, pp. 16-17.

9/ Ibid., p. 17; Kidd, et al., op. cit., p. 13.

storage." However, certain problems were noted: (1) there was a hot fall which delayed fruit cooling, and (2) the room was not gas tight.10/

To overcome the heating problem in 1922, the researchers turned to a system of cooling by using night temperatures (this is known as common storage in the U. S.).11/ This process enabled them to make a comparison between regular storage at different temperatures and gas storage during the 1922/23 season. Tests centered about holding Bramley's Seedling apples under the following conditions: (1) regular storage, 34°F (1°C), 85% humidity; (2) regular storage, 46°F (8°C), 60% humidity; and (3) gas storage, 46°F, 90% humidity. It was found that the commercial storage life was, respectively: (1) January, (2) March, and (3) June. The problem with fruit stored at 34° was low-temperature breakdown. This was reduced by raising the temperature but the storage life was still not long enough. The combination of gas storage and 46°F temperature brought about the desired results. The big practical problem that remained, however, was to find a good way of making the room gas-tight.12/

Following completion of a new building for the Low Temperature Research Station at Cambridge in 1922, a small experimental gas store was constructed for use during the 1923/24 season. This chamber was unique in that (1) provision was made for auxiliary mechanical refrigeration at the beginning of the season when the outside temperatures were relatively high, and (2) arrangements were made for gas-tightness by lining the room with galvanized iron and fitting it with a screw-down door. In basic components, it was the forerunner of commercial room design which was to follow. The chamber held about one ton of fruit and was erected inside a metal shed. With the refrigeration, it was possible to maintain a constant temperature of 7°C (45°F) over the entire eight-month storage season.13/

In 1927, Kidd and West summarized their work to date in their classic bulletin on the Gas Storage of Fruit (cited in fn. 3). In the opening pages they acknowledged that "The idea of using artificial atmospheres for the purpose of preserving fruit is by no means new." But they went on to point out -- and rightly so -- that their report "describes one of the first open

10/ "Fruit and Vegetable Committee," Report of the Food Investigation Board, 1922 (Department of Scientific and Industrial Research), 1923, pp. 28-29.

11/ J. C. Fidler, "Controlled Atmosphere Storage of Apples," The Journal of Refrigeration, London, August 1965 (Vol. 8, No. 8), pp. 265-273 (to appear in the Proceedings of the Institute of Refrigeration, London, in press).

12/ "Fruit and Vegetable Committee," Report of the Food Investigation Board, 1923 (Department of Scientific and Industrial Research), 1924, pp. 38-39.

13/ "Cold Storage and 'Gas' Storage Trials with Apples," Report of the Food Investigation Board, 1924 (Department of Scientific and Industrial Research), 1925, pp. 57-59. Also Kidd, et al., op. cit., p. 26.

scientific attacks upon the problem of the composition of the storage atmosphere upon fruit in storage." The report ~~was~~ a milestone in the development of CA storage and helped draw both scientific and commercial attention to the process.

During the next few years, work on apples continued. But other fruits were not overlooked. Barker reported on experiments with Navel oranges in 1928,^{14/} Trout summarized work on pears in 1930,^{15/} and Kidd and West reported on bananas in 1932.^{16/} It ~~was~~ found that pear life could be extended 50% in gas storage.

A sequel to Kidd and West's bulletin ~~was~~ published in 1930.^{17/} Also during 1930, a new experimental CA facility, the Ditton Laboratory, ~~was~~ erected near the East Malling Horticultural Research Station in Kent, one of the leading fruit growing areas. The new laboratory made it possible to carry out larger-scale tests than at Cambridge; Dr. West ~~was~~ placed in charge.^{18/}

The first commercial storage appears to have been constructed by a grower near Canterbury in Kent in 1929. The London Times carried a favorable account of the quality of the fruit when the storage ~~was~~ opened in late March, 1930.^{19/} Thereafter, there ~~was~~ a rapid expansion of commercial gas storage; commercial capacity reached nearly 100,000 bu. by 1932, over 375,000 bu. by 1934, about 1.2 million by 1936, and approximately 1.8

^{14/} J. Barker, "Storage of Navel Oranges in Controlled Atmosphere," Report of the Food Investigation Board, 1927 (Department of Scientific and Industrial Research), 1928, p. 63.

^{15/} S. A. Trout, "Experiments on the Storage of Pears in Artificial Atmospheres," Journal of Pomology and Horticultural Science, January 1930 (Vol. 8, No. 1), pp. 78-91.

^{16/} F. Kidd and C. West, "The Influence of Carbon Dioxide, Oxygen and Rate of Ventilation of the Storage, Ripening and Respiration of Bananas," Report of the Food Investigation Board, 1931 (Department of Scientific and Industrial Research), 1932, pp. 100-103.

^{17/} Franklin Kidd and Cyril West, "The Gas Storage of Fruit. II. Optimum Temperatures and Atmospheres," Journal of Pomology and Horticultural Science, January 1930 (Vol. 8, No. 1), pp. 66-67.

^{18/} C. West, "The History of Refrigerated Gas Storage for Horticultural Produce," Proceedings of the Eighth International Congress of Refrigeration, London, 1951, p. 407.

^{19/} Ibid.; "'Gas' Storage of Apples," The Times (London), March 24, 1930, p. 20 (col. 6).

million by the outbreak of war in 1939. Part of the space as of 1936 was to be used for pears.^{20/} By 1938, there were over 200 gas storages in England.

A farmers' bulletin by Kidd and West in 1935 suggested that the most economical capacity for a large grower was about 50 tons (2,500 bu.). An appendix offered, for the first time, some figures on "The Cost of Gas Storage." The bulletin stated that the main reason for the striking expansion was, as suggested earlier, that the relatively high temperatures made possible in gas storage avoided the low temperature problems which affected many British varieties.^{21/}

B. United States

The work of Kidd and West did not go unnoticed in the United States. The first American group to initiate research on CA storage was located at the University of California at Davis. In the spring of 1928, E. L. Overholser of the Pomology Department presented a talk to a warehousemen's convention on "Some Limitations of Gas Storage of Fruits."^{22/} He mentioned the work of Fulton and Hill in the U. S., reviewed Kidd and West's findings, and then went on to report some preliminary findings of a small-scale test on Fuerte avocados. Apparently his investigations were not carried any further.

In 1930, Professor Overholser left the University and F. W. Allen was assigned responsibility for fruit storage work. Professor Allen had been working, quite independently of Overholser, on some storage and transportation problems with artificial atmospheres. He had become interested in CA through his earlier work in Yakima (previously noted) and through knowledge of Kidd and West's findings. He focused his attention on the Yellow Newtown variety which, like the English apple varieties, was subject to low temperature injury. Following preliminary trials at Davis, a commercial test -- the first of its kind in the U. S. -- was set up in the fall of 1933 at the National Ice and Cold Storage Company in Watsonville. Some 4,000 boxes of fruit were included.^{23/} The results indicated the

^{20/} F. Kidd and C. West, "Recent Advances in the Work on Refrigerated Gas Storage," Journal of Pomology and Horticultural Science, January 1937 (Vol. 14, No. 4), pp. 304-305; West, op. cit., p. 409. The data for 1932-1936 were estimated from a chart presented by Kidd and West; the 1939 estimate was derived from data in West.

^{21/} Franklin Kidd and Cyril West, The Refrigerated Gas Storage of Apples, Department of Scientific and Industrial Research, Food Investigation Leaflet No. 6, 1935, p. 4.

^{22/} Ice and Refrigeration, June 1928 (Vol. 74, No. 6), pp. 551-552.

^{23/} Letters from F. W. Allen (Professor Emeritus), University of California (Davis), Department of Pomology, September 22 and November 3, 1966.

possibilities of CA storage and were published in 1935.^{24/} Further work was conducted during the next several years.

About the time Allen set to work on storage in Davis, a member of the Boyce Thompson Institute for Plant Research in New York State reported on a laboratory study of "The effect of carbon dioxide on respiring plant organs -- fruits, vegetables, and flowers -- stored for short periods." The concentration of carbon dioxide tolerated by each organ was examined for six temperatures varying from 30° to 77°F (0° to 25°C). Favorable effects were noted for bananas and many flowers. The project was financed by the Dry Ice Corporation of America.^{25/}

In 1935, Allen was joined by Dr. R. M. Smock, who worked with him about a year and a half. The work on apples was broadened to include pears, plums, and peaches. A report of this research was published in 1938.^{26/} Late in 1936 and early in 1937, Allen visited England and spent some time with Kidd and West. In February 1937, Smock moved to Cornell University to take up work in the post-harvest physiology of fruit. Allen continued his studies at Davis.^{27/}

At Cornell, Smock was assisted by A. Van Doren, a graduate student, who was to do his Ph.D dissertation on CA storage. Smock and Van Doren realized that McIntosh developed a disorder known as brown core when held for extended periods in ordinary (31° to 32°F) cold storage. Therefore, they conducted their first series of tests during the 1937/38 season on it and the Northwestern Greening. Their results were reported in August 1938.^{28/}

24/ F. W. Allen and L. R. McKinnon, "Storage of Yellow Newtown Apples in Chambers Supplied With Artificial Atmospheres," Proceedings of the American Society for Horticultural Science for 1934 (Vol. 32), 1935, pp. 146-152.

25/ Norwood C. Thornton, "Carbon Dioxide Storage of Fruits, Vegetables, and Flowers," Industrial and Engineering Chemistry, November 1930 (Vol. 22, No. 11), pp. 1186-1189. (This was the first of a long series of studies on the basic physiological influences of controlled atmospheres.)

26/ F. W. Allen and R. M. Smock, "Carbon Dioxide Storage of Apples, Pears, Plums, and Peaches," Proceedings of the American Society for Horticultural Science for 1937 (Vol. 35), 1938, pp. 193-199.

27/ His subsequent work led to the following articles in the Proceedings (Ibid.): "Influence of Carbon Dioxide in Lengthening the Life of Bartlett Pears," (Vol. 37), pp. 473-478; "Carbon Dioxide Storage for Yellow Newtown Apples," (Vol. 40), pp. 193-200.

28/ R. M. Smock and A. Van Doren, "Preliminary Studies on the Gas Storage of McIntosh and Northwestern Greening," Ice and Refrigeration, August 1938 (Vol. 95, No. 2), pp. 127-128.

That summer Smock spent three months in England with Kidd and West. Shortly thereafter, he reported on the situation in the United Kingdom and reviewed the work at Cornell.^{29/} Studies continued during the next several years with periodic reports.^{30/} While apples were emphasized in the Cornell efforts, ~~some~~ work ~~was~~ done on strawberries and cherries.^{31/}

In June 1941, Smock and Van Doren presented a detailed report of their findings in a comprehensive bulletin entitled Controlled-Atmosphere Storage of Apples.^{32/} The bulletin ~~was~~ a milestone for CA storage in the United States. Not only did it present the results of research on atmospheres, temperatures, and varietal response, but it went on to discuss room construction and operation. The report, like Kidd and West's study in England, did much to focus scientific and commercial attention on the CA process.

In addition to the research efforts in California and New York, several other groups ~~were~~ also studying CA storage for fruits. Work ~~was~~ initiated at Iowa State on apples during the 1938/39 season, and two reports were subsequently presented.^{33/} Work on citrus fruit in Florida^{34/} and on oranges

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- 29/ R. M. Smock, "The Possibilities of Gas Storage in the United States," Refrigerating Engineering, December 1938 (Vol. 36, No. 6), pp. 366-368.
 - 30/ R. M. Smock and A. Van Doren, "Studies With Modified Atmosphere Storage of Apples," Refrigerating Engineering, September 1939 (Vol. 38, No. 3), pp. 163-166; A. Van Doren, "Physiological Studies With McIntosh Apples in Modified Atmosphere Cold Storage," Proceedings of the American Society for Horticultural Science for 1939 (Vol. 37), 1940, pp. 453-458.
 - 31/ A. Van Doren, M. B. Hoffman, and R. M. Smock, "Carbon Dioxide Treatment of Strawberries and Cherries in Transit and Storage," Proceedings of the American Society for Horticultural Science (Vol. 38), 1941, pp. 231-238.
 - 32/ Cornell University, Agricultural Experiment Station, Bulletin 762, June 1941, 45 pp. This bulletin ~~was~~ the first publication to systematically adopt the now commonly accepted term of controlled atmosphere. Previously, as the foregoing footnotes suggest, "gas" and "modified atmosphere" were used. (An Extension bulletin of the ~~same~~ title ~~was~~ published in February 1949; No. 759, 39 pp.)
 - 33/ D. V. Fisher, "Storage of Delicious Apples in Artificial Atmospheres," Proceedings of the American Society for Horticultural Science for 1939 (Vol. 37), 1940, pp. 459-462; H. H. Plagge, "Controlled-Atmosphere Storage for Jonathan Apples as Affected by Restricted Ventilation," Refrigerating Engineering, April 1942 (Vol. 43, No. 4), pp. 215-220.
 - 34/ A. L. Stahl and J. C. Cain, Cold Storage Studies of Florida Citrus Fruit. III. The Relation of Storage Atmosphere to the Keeping Quality of Citrus Fruit in Cold Storage, Florida Agricultural Experiment Station, Bulletin 316, October 1937, 44 pp.

in California 35/ was reported in 1937. Studies on apples and cranberries were initiated in Massachusetts in 1940.36/

Instead of studying stationary storage, U. S. Department of Agriculture researchers concentrated on physiological studies of the effect of carbon dioxide on horticultural crops 37/ and on pre-storage and pre-transportation treatments.38/ These subjects, however, are outside the scope of this paper.

C. British Empire

Following the United Kingdom and the United States, Canada seems to have been the next to take up research on CA. Canadian work appears to have been started by M. B. Davis in 1933 at the Central Experimental Farm of the Canada Department of Agriculture. In the summer of 1933, Charles Eaves, working under Davis, initiated tests on strawberries and raspberries.39/ Subsequent studies by Davis and D. S. Blair centered about holding McIntosh.

35/ Rudolf M. Samisch, "Observations on the Effect of Gas Storage Upon Valencia Oranges," Proceedings of the American Society for Horticultural Science for 1936 (Vol. 34), 1937, pp. 103-106.

36/ See "Apple Storage Investigation," "Cranberry Storage Investigation," Annual Report (for 1940), Massachusetts Agricultural Experiment Station, Bulletin 378, February 1941, p. 58.

37/ See, for example: Erston V. Miller and Charles Brooks, "Effect of Carbon Dioxide Content of Storage Atmosphere on Carbohydrate Transformation in Certain Fruits and Vegetables," Journal of Agricultural Research, October 15, 1932 (Vol. 45, No. 8), pp. 449-459; Erston V. Miller and Oscar J. Dowd, "Effect of Carbon Dioxide on the Carbohydrates and Acidity of Fruits and Vegetables in Storage," Journal of Agricultural Research, July 1, 1936 (Vol. 53, No. 1), pp. 1-7.

38/ Charles Brooks, a plant pathologist, was associated with most of this work. He did not see much prospect for stationary CA storage beyond its use for a few varieties such as McIntosh. See C. Brooks, et al., Effect of Solid and Gasous Carbon Dioxide Upon Transit Disease of Certain Fruits and Vegetables, U. S. Department of Agriculture, Technical Bulletin 318, September 1932, p. 6; Charles Brooks, "Modified Atmospheres for Fruits and Vegetables in Storage and in Transit," Refrigerating Engineering, October 1940 (Vol. 40, No. 4), pp. 233-236.

39/ Charles A. Eaves, "The Present Status of Gas Storage Research With Particular Reference to Studies Conducted in Great Britain and Preliminary Trials Undertaken at the Central Experimental Farm, Canada," Scientific Agriculture, April 1935 (Vol. 15, No. 8), pp. 548-554.

It was felt that results of work during the 1933/34 and 1934/35 seasons indicated that "There are commercial possibilities in the storage of this variety." In September 1935, it was reported that a semi-commercial test was planned for the 1935/36 season.^{40/} An article the following year stated:

Apples taken from the gas stores as late as March 15th were equally as good as McIntosh normally are on December 1st, with the added advantage that on removal from gas storage to higher temperatures the fruit keeps much better than fruit from ordinary cold storage.^{41/}

A bulletin issued in 1939 suggests that the experiments had been carried out in a 150-bushel chamber.^{42/}

Elsewhere in the British Empire, research was initiated in Australia in 1935 on apples and peaches,^{43/} and in New Zealand in 1937.^{44/} Research was also started in 1935 in Denmark^{45/} and in 1938 in the Netherlands.^{46/}

The first commercial room, however, was built in none of these places. Rather, it was erected in 1935 in Elgin, South Africa, by E. B. F. and

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- 40/ M. B. Davis and D. S. Blair, "Harvesting and Storage of McIntosh and Fameuse Apples," Canadian Horticulture and Home Magazine (fruit edition), September 1935 (Vol. 58, No. 9), p. 206.
- 41/ M. B. Davis and D. S. Blair, "Cold Storage Problems with Apples," Scientific Agriculture, November 1936 (Vol. 17, No. 3), p. 113.
- 42/ W. R. Phillips, Gas Storage, Canada Department of Agriculture, Circular 149 (Pub. 670), December 1939, p. 4.
- 43/ S. A. Trout, G. B. Tindale, and F. E. Huelin, Investigations on the Storage of Jonathan Apples Grown in Victoria, Council for Scientific and Industrial Research, Bulletin No. 135, 1940, p. 87; F. E. Huelin, G. B. Tindale, and S. A. Trout, "The Cool Storage of Peaches in Air and Artificial Atmospheres," The Journal of the Department of Agriculture (Victoria), December 1937 (Vol. 35, No. 12), pp. 609-610. (The researchers had visited England and were familiar with the work done there.)
- 44/ Letter from C. S. Padfield, Fruit Research Orchard, Department of Scientific and Industrial Research, Havelock North, September 26, 1966.
- 45/ P. Molls Rasmussen, "Gas Storage of Apples in Denmark," Proceedings of the Eighth International Congress of Refrigeration, London, 1951, p. 410.
- 46/ T. Van Hiele, "Gas Storage of Fruits in the Netherlands," Proceedings of the Eighth International Congress of Refrigeration, London, 1951, p. 420.

H. A. Molteno. It was designed by the brother of a British scientist who had done much work on gas-tightness of CA rooms. The Molteno storage ~~was~~ larger than anything hitherto constructed in England. In view of the fact that the smaller English rooms had sealing problems, a radically new approach ~~was~~ taken. A large outside metal shell was constructed (180 ft. x 62 ft. 6 in., x 24 ft.) and the insulation placed inside it. From the outside, the building presented a most striking appearance.^{47/} Another storage ~~was~~ built by the Elgin Fruit Packers Cooperative in 1936. Neither CA storage, however, gave very promising results, and they were eventually converted into regular storage operations. One factor ~~was~~ that the important apple varieties stood up well in regular storage.^{48/} Dr. Kidd and F. W. Allen visited the Molteno storage in September 1936.^{49/} South African research work ~~was~~ reported in 1940.^{50/}

Subsequently, a commercial CA storage was constructed at Port William, Nova Scotia, Canada, in 1939.^{51/}

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In looking back on the period from World War I to World War II, then, we see a period of intensive scientific activity. The initial studies were done by Kidd and West in England. Their work led to research programs in the United States, Canada, and several other European nations. In England, the first commercial room was erected about a decade after research had started; thereafter, however, growth ~~was~~ rapid. The growth of commercial storage in the United States followed much the ~~same~~ pattern and will be the subject of the next chapter.

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- ^{47/} E. A. Griffiths, "All-Steel Gas Store for Fruit," Ice and Cold Storage (U.K.), May 1936 (Vol. 39, No. 458), pp. 67-69. Reprinted in Refrigerating Engineering, April 1937 (Vol. 33, No. 4), pp. 239-241. The British scientist, Dr. Ezer Griffiths, was connected with the National Physical Laboratory, which had worked with Kidd and West for many years (letter from J. C. Fidler, Ditton Laboratory, U. K., October 25, 1966).
- ^{48/} Letter from L. Ginsburg, Cold Storage and Transport Section, Fruit and Food Technology Research Institute, Department of Agricultural Technical Service, Stellenbosch, September 29, 1966.
- ^{49/} Allen, op. cit. (1966).
- ^{50/} Ginsburg, op. cit. The work ~~was~~ done by Dr. W. E. Isaac of the Low Temperature Research Station in Capetown.
- ^{51/} Letter from L. P. S. Spangelo, Fruit Unit, Central Experimental Farm, Canada Department of Agriculture, Ottawa, October 6, 1966 (based on note by C. A. Eaves, Kentville, N. S.).

IV. APPLE STORAGE IN THE UNITED STATES

The research reported in the previous chapter provided the basis for commercial use of controlled atmosphere storage in the United States. Although CA is now being considered for many fruits, most of the experience from 1940 to 1966 was with apples. Therefore, in this chapter we will turn our attention to CA storage of this item. There was a great increase in research during this period and no attempt will be made to chronicle all of it; the interested reader is instead directed to reviews and bibliographies prepared by members of the Market Quality Research Division of the U. S. Department of Agriculture.^{1/}

A. The 1940's

CA storage for apples had its birth and early start in New York State. In fact, from 1940 to 1950 all of the commercial CA storage in the United States was in New York, and almost entirely in the Hudson Valley. The reasons for growth in this area center about (1) the research done by Drs. Smock and Van Doren; (2) the need for longer storage and shelf life for the McIntosh, one of the principal varieties;^{2/} and (3) the presence of some progressive growers who owned storages.

With the encouragement of Smock and Van Doren, the first three CA rooms were put into operation in 1940. All represented remodeling of existing cold storage rooms. One was on the farm of Claude Hepworth in Milton, in the Hudson Valley. The capacity -- 14,000 bu. -- was quite large by English standards. For the first several seasons, difficulty was experienced

1/ A Review of Literature on Harvesting, Handling, Storage and Transportation of Apples, U. S. Department of Agriculture, Agricultural Research Service, ARS 51-4, August 1965, pp. 85-102; R. E. Hardenburg, "Developments on Postharvest Use of Controlled or Modified Atmospheres for Quality Retention of Horticultural Crops," Proceedings, Eastern Experiment Station Collaborators Conference on Post-Harvest Physiology, U. S. Department of Agriculture, Agricultural Research Service (EURDD), October 1964, pp. 7-16. The Division maintains a current card file on CA research reports.

2/ Under normal storage conditions McIntosh could not be held with assurance after January: they were not only subject to a low-temperature disorder known as brown core if held for long periods, but their shelf life was apt to be very short (shelf life is the period of time apples remain marketable after they are removed from storage). In CA storage, McIntosh could be held at higher temperatures, thus avoiding brown core, and at the same time be kept into the summer and still have good shelf life.

in adequately sealing the room.^{3/} The second room was built on the farm of John A. Hall of Lockport, in the western portion of the State. Capacity was 2,000 bu., and sealing ~~was~~ also a problem.^{4/} The third room was established in the Sodus Cold Storage, also in western New York. The room held about 8,000 bu. and was the first to be constructed in a public storage. While the room worked satisfactorily, it remained in operation only two seasons because of economic factors.^{5/} In 1941, a fourth room was placed in operation on the M. G. Hurd & Sons farm in Clintondale, in the Hudson Valley. This room, unlike the others, represented new CA construction -- the first in the U. S. -- and was the first to get a good airtight seal. Capacity was about 7,500 bu.^{6/} During the period, Van Doren was assigned Extension responsibility for CA storage and worked closely with all four operators, especially the Hurds.^{7/}

There was a gradual growth in new capacity, all of it in the Hudson Valley, through the end of the decade. Smock continued to work with operators on

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- 3/ Dana G. Dalrymple, "Tree-Fresh Apples in May!," Farm Journal, May 1957, pp. 30-31, 158. (Where sealing or other problems existed, CA rooms could be operated as regular cold storages.)
 - 4/ LeRoy E. Fess, "W. N. Y. Fruit Preserved by Own Carbon Dioxide," Buffalo Evening News, October 10, 1940, p. 25; LeRoy E. Fess, "Apples are Awakened from a Deep Sleep to Meet Demands of Buffalo Market," Buffalo Evening News, April 19, 1941, p. 19; letter from D. M. Dalrymple, New York State Department of Agriculture and Markets (Dalrymple was one of the county agents who encouraged Hall to install his CA room; later they formed a partnership to buy another farm and put up the first truly operational CA storage in Western New York in 1956).
 - 5/ The storage could not charge enough more, because of the onset of WW II and price control, to cover the extra costs. L. B. Skeffington, "'Gas' Lengthens Apples' Life," Rochester Democrat and Chronicle, September 7, 1940, p. 23; conversation with W. Edward Bishop, Sodus Cold Storage, October 28, 1966; and a letter from Jerome Hurd, cited in next footnote.
 - 6/ "Gas Storage is the Making of the McIntosh Apple," Ulster County Farm and Home Bureau and 4-H Club News, October 1943, p. 9; letter from Jerome Hurd, October 14, 1966. Also see New York Herald Tribune: September 18, 1949, Sect. 2, p. 1; April 18, 1950, p. 20. The room has been operated for CA continuously and successfully since 1941, except for two seasons (1946/47, 1966/67) when there was a crop failure or shortage.
 - 7/ R. M. Smock, "The Future of Controlled Atmosphere Apples," Proceedings of the One Hundred and Second Annual Meeting of the New York State Horticultural Society, 1957, p. 209; ~~remarks~~ in the 1958 Proceedings, p. 194; letter, September 27, 1966.

their storage problems. Estimated capacity by years was:

1940	24,000 bu.	1945	65,500 bu.
1941	31,500	1946	76,500
1942	32,500	1947	86,500
1943	55,500	1948	87,500
1944	55,500	1949	99,500

Virtually all of the apples in CA storage were McIntosh.^{8/}

B. The 1950's

During the 1950's, CA storage of apples became commercially important and spread to other States, regulations were introduced, and increased attention was given to economic aspects.

1. General Situation

The real expansion in CA storage began in the early 1950's. In addition to a pronounced growth in New York State (including expansion into the Champlain Valley), CA storages were placed in commercial operation in New England in 1951; in Michigan and New Jersey in 1956; in Washington, California, and Oregon in 1958; and in Virginia in 1959.^{9/} During this period, varieties other than McIntosh began to be held in quantity.

In most cases, commercial operation was preceded by research on the response of local varieties to differing atmospheric conditions.^{10/} Generally this was done at the State University.^{11/} We have already noted that research in California dated back to 1930 and in Massachusetts to

^{8/} Modified from data provided by Dr. Smock and cited in Dana G. Dalrymple, Marketing Controlled Atmosphere Apples, Cornell University, Department of Agricultural Economics, A. E. 1028, June 1956, pp. 4-7.

^{9/} Based on International Apple Association storage reports. Estimates of holdings by States by year are presented in Table 1, p. 35.

^{10/} One prospective New York operator, F. Palmer Hart of Red Hook, visited the Ditton Laboratory in England before constructing his storage; the operators of a Watsonville, Calif., CA storage were also in contact with Ditton (letter from J. C. Fidler, Ditton Laboratory, U. K., October 25, 1966; conversation with F. Palmer Hart, October 27, 1966).

^{11/} Many of the individuals initiating this research had received their Ph.D.'s in horticulture from Cornell: Frank Southwick in Massachusetts, George Mattus in Virginia, Donald Dewey in Michigan, Archie Van Doren in Washington, and Robert Hardenburg of the U. S. Department of Agriculture. Mattus did his dissertation under Smock on CA storage of pears.

1940. Mattus initiated work in Virginia during the 1949/50 season;^{12/} Van Doren reported to the Washington State Horticultural Association in 1952 on the storage of Delicious;^{13/} Dewey initiated studies on Jonathan in Michigan during the 1954/55 season (in cooperation with I. J. Pflug);^{14/} and the U. S. Department of Agriculture started work in Washington State in 1953.^{15/} Dr. Smock's work in New York State was facilitated in 1953 with the completion of a large new storage designed specifically to accommodate studies on controlled atmosphere storage.^{16/}

By the 1955/56 season, total CA storage holdings had grown to about 814,000 bushels, some 684,000 or 84% being in New York, and the rest in New England. In the spring of that year, I did a study of the industry in New York which provides an insight concerning the nature of growth to that point.^{17/} I interviewed all 23 operators of storages in the State (and one in Vermont), as well as some wholesalers and retailers. Typically, CA storages were owned by large and successful fruit farmers. The average total CA holdings per farm were large -- averaging 31,200 bu. and ranging from 7,500 to 65,000 bu. Average room size was 10,800 bu. A little over three-quarters of the capacity represented new construction while the other quarter was remodeled from regular storage. A large proportion of capacity, about 68%, was rented out to other farmers or speculators. An attempt was made to put in the best fruit; it was usually tree-run and

^{12/} G. E. Mattus, "Regular and Automatic CA Storage," Virginia Fruit, June 1963, p. 41.

^{13/} Archie Van Doren, "The Storage of Golden Delicious and Red Delicious Apples in Modified Atmospheres," Proceedings of the Forty-eighth Annual Meeting of the Washington State Horticultural Association, 1952, pp. 91-95. Eugene T. Budiselich completed a M. S. thesis on this subject under Dr. Van Doren in 1951.

^{14/} D. H. Dewey, W. E. Ballinger, and I. J. Pflug, "Progress Report on the Controlled-Atmosphere Storage of Jonathan Apples," Quarterly Bulletin (Michigan Agricultural Experiment Station), May 1957 (Vol. 39, No. 4), p. 692. Jonathan apples do not have a long life in regular storage due to soft scald and Jonathan spot; the two problems were controlled in CA storage.

^{15/} H. A. Schomer and G. F. Sainbury, Controlled-Atmosphere Storage of Starkling Delicious Apples in the Pacific Northwest, U. S. Department of Agriculture, Agricultural Marketing Service, AMS-178, March 1957, p. 1.

^{16/} Dana G. Dalrymple, "World's Most Modern Apple Storage," American Fruit Grower, November 1954, pp. 6-7, 20.

^{17/} Dalrymple, op. cit. (1956), 59 pp.

stacked in boxes. Room openings began in March and continued through to June. Fruit was usually graded by hand and packed in cell cartons.

2. Initiation of Regulations

Through the middle 1950's, concern was growing about the devious actions of some storage operators who (a) marketed regular storage apples ~~as~~ CA apples, (b) did a poor job of maintaining required atmospheres, or (c) took apples out of CA storage early in the season before the physiological benefits of the process began to show up. Industry leaders felt that these actions would destroy the quality image of CA.

To prohibit such practices, legislative activity was initiated in New York in 1956. A general bill was introduced in the legislature early in 1957, and became law in April 1957. Following enactment, detailed rules and regulations were drawn up. These were discussed at a hearing in August 1957, and were promulgated on October 15, 1957. Among the individuals most responsible for getting the regulations through the legislature and in operation were D. M. Dalrymple, then Secretary of the New York State Horticultural Society, and Spencer Duncan of the New York State Department of Agriculture and Markets. The specific provisions were drawn up by Dr. Smock.

The basic regulations were that the desired atmosphere must be reached within 20 days of sealing the room, and that the product must be held at not more than 5% oxygen for a minimum of 90 days. Storage owners in the State (and those outside who planned to sell in New York) had to register with the State Department of Agriculture and Markets. They then had to report room sealing date and keep a daily record of atmospheric readings which would be available for review at the storage. Each registrant was given a number which was to be stamped on all containers and invoices.^{18/} Other areas recognized the value of these regulations, and by late 1964 similar versions were in effect in all but three States having CA storage (the exceptions were Vermont, Rhode Island and Oregon).^{19/}

Aside from the intended benefits of these regulations, there were several others which may be of interest. First, the requirement that daily records

18/ Based on the following sources: Spencer Duncan, "Proposed Legislation to Regulate Modified Atmosphere Storage," Proceedings of the One Hundred and Second Meeting of the New York State Horticultural Society, 1957, pp. 218-219; Joe Firth, "Controlled Atmosphere Regulations," Proceedings of the One Hundred and Third Meeting of the New York State Horticultural Society, 1958, pp. 192-193; letter from D. M. Dalrymple, New York State Department of Agriculture and Markets, September 15, 1966.

19/ "State Storage Regulations for Certified 'Controlled Atmosphere' Apples," U. S. Department of Agriculture, Federal Extension Service, December 1964, 3 pp. (originally prepared by the Fruit Branch, Consumer and Marketing Service, USDA).

be kept reduced the chances of making gross operating mistakes (there were several cases in early years where adequate oxygen levels were not maintained and the apples were lost). Secondly, CA storage made it possible to ship eastern and mid-western apples into California for the first time. For many years California had a quarantine on apples from these areas because of the possibility of bringing in insect pests (curculio and maggots). When it was demonstrated that these pests could not survive in controlled atmosphere, the regulation was withdrawn for apples from registered storages.^{20/} The first shipments of New York-New England McIntosh were received in Los Angeles in early February, 1961.^{21/}

Perhaps predictably, a few operators eventually wanted to have the 90-day regulation relaxed so that they could get CA McIntosh onto the market sooner.^{22/} However, the work of Smock and Elampied clearly demonstrated that McIntosh generally had to be held a minimum of 90 days before the quality was better than that of regular storage apples.^{23/} Industry leaders felt that it was essential to continue the quality reputation of CA fruit, and the proposed change received little support.^{24/}

In view of the regulations, few CA apples (other than some Jonathans) reach the market before January 1.

3. Studies of Economic Factors

Controlled atmosphere storage is obviously more expensive than regular cold storage. The higher costs center about higher construction costs (an

20/ Interstate Movement of Plants and Other Plant Pest Carriers, California, U. S. Department of Agriculture, Agricultural Research Service, Plant Quarantine Division, December 18, 1964, p. 23.

21/ "Eastern CA Macs at L. A. Make Spectacular Debut," The Produce News, February 10, 1961, p. 1.

22/ Apples can be taken out of CA storage before the end of the 90-day period, but they must be sold as regular storage fruit. (The 90-day regulation does not hold for Jonathan apples in Michigan which need to be held only 60 days.)

23/ R. M. Smock, "When Do CA Apples Outstrip Regular Storage Apples in Condition," Proceedings of the New England-New York Controlled Atmosphere Storage Seminar (April 9, 1964), University of Massachusetts, Cooperative Extension Service, Publication 422, pp. 61-64. Further studies on the matter by others were subsequently reported in "Is the 90-Day Requirement Realistic?," New York-New England Controlled Atmosphere Storage Seminar Proceedings (April 28, 1966), Cornell University, Department of Pomology, pp. 60-67. (Jonathan apples show higher quality after 60 days in Michigan.)

24/ Except for the preceding Seminar articles, discussion of this matter was conducted on an internal basis. I participated. The subject may well come alive again.

air-tight room, carbon dioxide scrubbing machinery, etc.), and operating costs (labor involved in checking the rooms, etc.). With the increase in CA storage during the 1950's, the question of whether these high costs were met by higher prices became a matter of more general interest.

The first researchers to look into the matter on a broad-scale basis were two economists from Washington State College. As no CA rooms were in operation in Washington, they collected data on New York McIntosh prices and synthesized cost figures. They concluded that under certain circumstances CA storage of Washington Delicious would be "economically feasible."^{25/}

In 1956, I examined prices of CA apples as part of the more general study noted earlier.^{26/} One price series for the 1944/45 to the 1950/51 period showed a net advantage of 98¢/bu. in favor of CA apples. However, this series did not allow for the facts that higher quality apples were put in CA storage and that they were usually packed by hand. Allowing a 55¢/bu. differential for these items (which I now think may have been too high), the net farm premium averaged 43¢. Prices on the New York wholesale market were particularly strong for CA apples during the spring of 1956 and the premium appeared to be two to three times as high.^{27/}

Subsequently, a far more intensive study was made in New York by John C. Thompson for the late 1950's. He found that during 1957/58 and 1958/59 the total annual storage costs for CA storage were 14¢/bu. higher than they were for regular storages. Wholesale prices over the 1953 to 1960 period, allowing for grade and package differences, averaged 86¢/bu. higher for CA fruit than they did for regular apples. If the added storage cost of 14¢/bu. for CA is subtracted from the price, it would appear that the premium for CA apples might have averaged about 62¢/bu. for those who owned storages. Those who rented space had to pay about 35¢/bu. extra -- leaving them a premium of 51¢/bu.^{28/} In either case, a slight additional

25/ J. E. Loudon and C. H. Zuroske, "Economics of Controlled Atmosphere Storage of Washington Apples," Proceedings of the Forty-ninth Annual Meeting of the Washington State Horticultural Association, 1953, pp. 77-84. (Loudon submitted a M.S. thesis with the same title in 1953.)

26/ Dalrymple, op. cit. (1956), pp. 37-40.

27/ Part of the reason was that prices during the early part of the regular storage season had been unusually depressed (Ibid., p. 21). In setting up my cost differential, I allowed an extra cost of 35¢/bu. for storage (at that time two-thirds of the space was rented), 60¢ for the quality differential (Fancy vs. No. 1) and hand grading, and 5¢ for commission.

28/ John C. Thompson Jr., Apple Storage Costs in New York State, Cornell University, Department of Agricultural Economics, A.E. Res. 87, March 1962, pp. 40-50. (This report was based on Thompson's Ph.D. dissertation of the same title.)

deduction probably should be made for a higher commission charge because of the higher sale price. If we arbitrarily pick a figure of 5¢, this would bring the premium to approximately 57¢/bu. for those who owned storages, and 46¢ for those who rented space.

Throughout the 1950's there was concern that the premium for CA apples might be a transitory thing -- that it would begin to decline as CA capacity increased. However, Thompson's study showed no decrease in the premium even with the increase in holdings.^{29/} The answer probably was that a new and higher demand curve was established for CA apples, reflecting their higher quality. The strong demand may also be traceable, in part, to a vigorous CA advertising and promotion program initiated in the spring of 1956 by the New York-New England Apple Institute.^{30/} Similar programs have since been initiated by other regional apple groups.

If we take an average premium of 50¢/bu. as possibly representative of the 1945/46 to 1960/61 period, and apply it to the quantities of apples held, we can get a very rough idea of the value of the CA premium alone to New York growers. During the 15-year period, total holdings were about 7.7 million bu. Assuming that about 20% of these apples were sorted out as utilities and culls, we might come up with a figure of 6.2 million bu. sold at the premium prices.^{31/} This would suggest added income to growers of some \$3 million. There were, of course, other advantages to growers such as greater flexibility in marketing their overall crop, alleviating the pressure of having to sell by a certain point because of fruit condition problems, etc.

C. The 1960's

Along with a marked expansion in CA holdings (which will be reported in detail in Section D), two of the more significant developments during the 1960's were the introduction of mechanical generating systems and the use of CA storage for processing apples.

1. Mechanical Generating Systems

Through 1960, all of the apples in CA storage were in what might be called a product-generated atmosphere. That is, the fruit itself used up the oxygen in the air and generated carbon dioxide. The storage operator would

29/ Ibid., p. 50.

30/ Dalrymple, op. cit. (1956), p. 24. The Institute uses "Crisp-Aire" as a trade name.

31/ The sort-out figure is based on an estimate gained from packers of CA apples during the spring of 1956 (Dalrymple, op. cit. (1956), p. 19). It may not be representative of the period but is the only such figure at hand.

let in outside air if the oxygen level got too low and run the atmosphere in the room through a scrubber if the carbon dioxide level got too high. In the 1960's, however, several relatively automatic mechanical generating systems were introduced.

a. Tectrol. The Tectrol system (Tectrol is an acronym for "total environmental control") was developed by the Whirlpool Corporation of Benton Harbor, Michigan.

Essentially it consists of an ignition chamber supplied with normal outside air and gas, either natural or propane, which are burned to remove most of the oxygen. This product is scrubbed of most of the carbon dioxide and then fed to the storage room. The system is operated continually so that the room atmosphere is constantly flushed to carry away the carbon dioxide produced by the fruit.^{32/}

This system grew out of work started by Whirlpool in 1958 to develop a better refrigerator. As the process appeared to be ahead of its time for the home market, the firm turned its attention to apple storage. Here was an area where the storage operators were quite familiar with the concept and where further growth could be expected. Apple storage also provided an avenue for further testing which could form the basis for application in other points in the distribution system, and indeed for other products.^{33/}

Following laboratory development, the system was field-tested during the 1961/62 season. Concurrently, a generator unit was placed under test by Dewey and Pflug at Michigan State University.^{34/} During the 1962/63 season the system was made commercially available on a lease basis. Installations covering some 500,000 bu. were made in Michigan, Washington, and Virginia.^{35/} Mattus worked with the Virginia installation and studies the effect of the mechanical system on fruit condition.^{36/} During the

32/ D. H. Dewey, "CA Storage in Michigan and Our Experience With Externally Generated Atmospheres," Proceedings of the One Hundred and Eighth Annual Meeting of the New York State Horticultural Society, 1963, p. 245.

33/ From information provided by Donald Ranum, Tectrol Division, Whirlpool Corporation, September 14, 1966.

34/ D. H. Dewey and I. J. Pflug, "The Storage of Apple Fruits in an Externally Generated Controlled Atmosphere," Quarterly Bulletin (Michigan Agricultural Experiment Station), February 1963 (Vol. 45, No. 3), p. 387.

35/ From information supplied by Ranum, op. cit.

36/ Mattus, op. cit., pp. 41-44.

1963/64 season, studies were taken up by Smock and Blanpied in New York State.^{37/}

Based on this experience, the external generator appeared to have several advantages and disadvantages when compared to the traditional system. Among the advantages were the following: (1) the storage room used did not have to be quite so tightly sealed; (2) there was a more rapid attainment of CA atmospheres at the start of the storage period; and (3) the room could be opened during the season for repairs or removal of fruit, and then resealed for continued operation. The main disadvantage was a somewhat higher cost.^{38/}

The advantages seem to have overcome any cost differential, for there has been a significant expansion in the use of the Tectrol system. From 500,000 bu. in 1962/63, Tectrol holdings expanded to 1.5 million bu. in 1963/64, 3.2 million in 1964/65, 4.2 million in 1965/66, and between 5 and 6 million in 1966/67. For the 1966/67 season, the generators were made available on a sale basis. Also, an additional model has been introduced which can be used for scrubbing only.^{39/}

b. Arcagen.^{40/} The Arcagen system (Arcagen is an acronym for Atlantic Research Controlled Atmosphere Generator) was developed by the

^{37/} G. D. Blanpied, "Research Results with Automatic Generators," Proceedings of the New England-New York Controlled Atmosphere Storage Seminar (April 9, 1964), University of Massachusetts, Cooperative Extension Service, Publication 422, pp. 25-28; R. M. Smock and G. D. Blanpied, "Effect of Modified Techniques in CA Storage of Apples," Proceedings of the American Society for Horticultural Science, 1965 (Vol. 87), pp. 73-77.

^{38/} On the matter of cost, see: Dewey, op. cit., p. 246; G. D. Blanpied and R. M. Smock, "New Techniques in CA Storage," Proceedings of the One Hundred and Eighth Annual Meeting of the New York State Horticultural Society, 1963, p. 251; David Everett, "Comparison of the Cost of Conventional C. A. With Tectrol in Our Storage," Proceedings of the One Hundred and Tenth Annual Meeting of the New York State Horticultural Society, 1965, pp. 135-140.

^{39/} Letters from Richard Sawyer, Tectrol Division, Whirlpool Corporation, October 7 & 28, 1966; R. A. Ferguson, "Tectrol System," New York-New England Controlled Atmosphere Storage Seminar Proceedings (April 28, 1966), Cornell University, Department of Pomology, pp. 1-3. (Hereinafter referred to as 1966 Seminar Proceedings.)

^{40/} This section is based on material provided by W. Paul Jensen, Atlantic Research Corporation, September 7, 23, October 25, 1966. The technical aspects of this process are discussed by Jensen in "Controlled Atmosphere Generators for Fresh Fruit and Produce Storage," Transactions of the ASAE (American Society of Agricultural Engineers), St. Joseph, 1966 (Vol. 9, No. 4), pp. 449-454. A more general article by Jensen appeared in Produce Marketing, April 1965, pp. 43-44, while a talk by Owen Thomas was reported in the 1966 Seminar Proceedings, pp. 4-7.

Atlantic Research Corporation of Alexandria, Virginia. Atlantic's entry into storage systems was an outgrowth of their work on atmosphere equipment for nuclear submarines. The Arcagen system differs from Tectrol in that instead of continuously flushing the room with a gas mixture, the room atmosphere is continuously recirculated through the generator equipment. The two basic units of the Arcagen system are an Arcosorb carbon dioxide scrubber and an Arcat oxygen converter. The Arcat unit converts oxygen into carbon dioxide and water vapor by catalytically burning it with a gaseous fuel.

The units can be used separately or in combination with each other. The Arcosorb scrubber was commercially introduced and used during the 1963/64 season on some 560,000 bu. The Arcat converter was not introduced until the 1965/66 season. The Arcosorb and Arcat units were then either used in combination (forming the Arcagen system) or the Arcat converter was used by itself (with some other system used for carbon dioxide scrubbing). During 1965/66, total U. S. capacity under each option was as follows: Arcagen system, 670,000 bu.; Arcat converter, 320,000. During the 1966/67 season the comparable figures were: Arcagen, 1.23 million; Arcat, 1.25 million. The Arcagen system is concentrated in Washington and Pennsylvania; the Arcat unit in Washington, New York, and Michigan. An Arcagen system was installed for one CA room at Cornell for testing purposes during the 1965/66 season.

The advantages and disadvantage of the Arcagen system compared with conventional CA storage appear to be about the same as for Tectrol.

c. Other Systems. A modification of the Polarstream intransit refrigeration process has been tested for use in stationary storage. (Polarstream is manufactured by the Linde Division of Union Carbide Corporation.) The tests were carried out by Drs. Smock and Blampied at Cornell during the 1963/64 season and appeared promising.^{41/} The process centers about the use of nitrogen. As yet, there are no known commercial installations.^{42/}

There is at least one other generator on the market, but it has apparently received limited use to date.^{43/} Several additional systems for oxygen control are under development at the public level.^{44/}

41/ For details see R. M. Smock and G. D. Blampied, "The Use of Nitrogen for Cooling, Flushing and Maintaining Atmospheres in CA Rooms," Proceedings of the One Hundred and Tenth Annual Meeting of the New York State Horticultural Society, 1965, pp. 140-145.

42/ Nitrogen gas, by itself, has been used for some time in the U. S. and abroad for an initial quick "pull-down" of room atmospheres.

43/ It is produced by the Gas Atmosphere Division of Alco Standard Corporation, Cleveland. See W. H. Boyd, "Gas Atmospheres," 1966 Seminar Proceedings, pp. 8-9. There is one installation in Massachusetts.

44/ John Zahradnik and Athanasios Kiratsous, "A Method for Oxygen Removal from CA Storages," C. A. Eaves, "Oxygen Controller for CA Storage," (cont.)

* * *

Mechanical generators have, in sum, become a significant part of controlled atmosphere storage. The Tectrol and Arcagen systems together covered some 5 million bushels of apples during the 1965/66 season -- nearly 40% of total CA holdings. The proportion increased substantially during the 1966/67 season.^{45/} In some recent cases, generators have been used to supplement regular CA operations (primarily for a quick pull-down).^{46/}

2. Use for Processing

Over the years, essentially all CA apples have been held for the fresh market. However, a certain portion of CA apples have ended up being processed. These have generally been the grade-outs from fresh pack operations. In a few cases, apples have been sold to processors because of a low fresh market price or because of quality problems.

The bulk of canned apple processing is done before December.^{47/} However, some processing for freezing is done through the winter and even spring months. The reason for the longer season on freezing is that some

(cont.) 1966 Seminar Proceedings, pp. 10-24. (It should be noted that Eaves, a Canadian who has been involved with CA since the early thirties (see Chp. III, Sect. C), has been responsible for a number of significant technical innovations such as a dry lime scrubber and a gas-tight plastic storing unit. Zahradnik has also made several contributions of an engineering nature.)

45/ It is not possible precisely to specify total current holdings under generators. While the Tectrol figures were quite accurate prior to 1966/67 because rent for the generator was paid on a bushels stored basis, the switch to the sale of generators removed this source of information. The Arcagen estimates refer to capacity and reflect, as has been noted, two types of systems.

46/ Those who are interested in more details on generators may wish to consult: Robert M. Smock, "The Pros and Cons of Generators for CA Storage," Proceedings of the One Hundred and Eleventh Annual Meeting of the New York State Horticultural Society, 1966, pp. 129-131; D. H. Dewey, "Results With CA Generators in Michigan," and G. D. Blanpied and R. M. Smock, "New York Results With CA Generators," 1966 Seminar Proceedings, pp. 25-34.

47/ Over the ten-year period from 1954 to 1963, nearly 83% of the canned sauce and 72% of the canned slices were packed before December (Dana G. Dalrymple and Irvin C. Feustel, Recent Developments in the Production and Marketing of Apple Sauce and Slices, U. S. Department of Agriculture, Federal Extension Service, July 1965, p. 9).

operators consider it cheaper to store fresh apples than the frozen product. Hence, it is freezers who ~~are~~ most likely to hold apples in storage.48/

While scattered freezers have held relatively small lots of apples in CA from time to time, the first one to do it on a systematic basis and on a large scale was Layton Stockdale of the Zero-Pack Company in Winchester, Virginia. For the 1962/63 season, Stockdale had one of his rooms converted to CA operation -- using generators -- and held 70,000 bushels, mainly Stayman. He ~~was~~ interested in CA because regular storage didn't hold the fruit quite long enough in the condition he wanted; with CA he would be able to extend his processing season several months. The experiment turned out to be a success, and during the 1963/64 season he added another room of 60,000 bu. in which he held Yorks.49/ This gave him total capacity for 130,000 bushels. He has found that the extra costs of CA are far outweighed by the savings he is able to make by extending his present packing period. In this way he is also able to expand the volume processed without having to go through the very expensive step of buying larger machinery.50/

Another freezer has recently looked into this matter. During the 1965/66 season, W. J. Klotzbach of Cherry Growers Inc. in Traverse City, Michigan, maintained records for yard, refrigerated, and CA storage. Considering fruit product yield and labor cost, the combined processing cost for a pound of fresh slices appeared to be about 19% less for CA apples than for those held in yard storage and 7% less than for apples held in refrigerated storage. While these estimates were admittedly rough, Klotzbach felt that the savings in processing costs more than offset the increased cost of CA storage. He also noted the advantage cited previously -- the possibility of lengthening and evening out the processing season. During the 1966/67 season, the firm plans to make use of 60,000 bu. of CA apples.51/

48/ However, a California storage operator reports storing processing apples over a 13-month period for fresh apple pies ("Modified Atmospheres; A Panacea for Produce?", Western Grower and Shipper, May 1964, p. 10).

49/ The York room is not run under full CA all season. While it has some generators it doesn't have full capacity. But the Staymans ~~are~~ used first and so when that room is empty, the generators ~~are~~ switched to the York room.

50/ Based on: conversations with Layton Stockdale, September 20, November 4, 1966; and G. E. Mattus, "Controlled Atmosphere Storage in Virginia," Virginia Fruit, August 1964, p. 20.

51/ Statement of W. J. Klotzbach in Processing an Expanding Apple Crop (Proceedings of the National Apple Industry Utilization Conference, March 1966, ed. by D. G. Dalrymple and B. A. Twigg), University of Maryland, Department of Horticulture, July 1966, pp. 88-89; letter from Klotzbach, October 25, 1966.

On the basis of this information, it would seem that the future may see expanded storage of CA apples for late-season processing into frozen slices.

3. Studies of Economic Factors

One of the recurrent economic questions pertaining to CA storage for apples is: how further can it be expected to expand? This is difficult to answer, but one approach may be made in terms of elasticity of demand.

In 1962, I reported on a study of the variations in the price elasticity of demand for all fresh apples at retail for the 1953 to 1957 period as indicated by the Michigan State Consumer Panel in Lansing. At this time, there were very few CA apples on the market in Lansing. The results were as follows:

Period I (October-December)	- 2.34
Period II (January-March)	- 1.31
Period III (April-June)	- 4.57

Briefly, this indicated that the demand for apples was relatively less elastic in period II than in periods I and III. This implied that with larger quantities of apples, they could be marketed either earlier or later in the season with less depressing effect on prices than in mid-winter.^{52/}

A similar analysis was subsequently made by Ben-David and Tomek in New York for the 1960/61 to 1963/64 seasons. Their study differed in that it examined farm rather than retail elasticities and it covered a situation where CA sales were significant. They divided the season into three parts and obtained the following elasticities (transformed from flexibilities):

Period I (September-November)	- 2.71
Period II (December-February)	- 1.08
Period III (March-May)	- 2.18

The periods differed by one month, but the general relationship was the same: elasticity was lowest in mid-season and higher later in the season. Ben-David and Tomek drew the same implications as I did: that it would be better to market increased quantities either earlier or later in the season.^{53/}

52/ Dana G. Dalrymple, "Economic Aspects of Apple Marketing in the United States," Michigan State University, Department of Agricultural Economics, Ph.D. dissertation, 1962, pp. 238-253. The original data also included an estimate for the July-September period but I omitted it to simplify the presentation.

53/ Shaul Ben-David and William G. Tomek, Storing and Marketing New York State Apples, Based on Intraseasonal Demand Relationships, Cornell University, Agricultural Experiment Station, Bulletin 1007, November 1965, pp. 12-18. (Based on Ben-David's Ph.D. dissertation.) A similar pattern of elasticities at the wholesale level has recently been reported by R. E. Moffett, et al., in Economic Benefits of Optimum (cont.)

Just how many more apples might be sold later in the season is, of course, the big question. Ben-David and Tomek worked out an optimal redistribution for each of the four years covered by their study. The increases for New York were as follows for period III: 1960/61, +696,000 bu.; 1961/62, +235,000 bu.; 1962/63, +289,000 bu.; 1963/64, +284,000 bu.^{54/} The quantities were not very large and tended to decrease (at the same time as New York CA capacity increased). It might be deduced that New York, at least, was getting near its optimum CA capacity. Of course, as production increases, certain increases in CA capacity will be needed.^{55/}

The next steps in a study of this type might be a breakdown by varieties and an extension to a wider geographical area.

D. Statistical Review

Perhaps one of the better ways of gaining an idea of the changes that have taken place in CA storage of apples in the U. S. during the post-war period is to review the statistics pertaining to storage holdings. The International Apple Association (IAA) has issued comprehensive monthly estimates since 1952, which include both variety and State breakdowns.^{56/} We shall

(cont.) Intraseasonal Allocation of New England-New York McIntosh Apples, University of Connecticut, Agricultural Experiment Station, Bulletin 394, June 1966, p. 11.

^{54/} Ibid., p. 16.

^{55/} Ben-David and Tomek went on to make a projection of the approximate magnitude of CA storage that might be optimal in New York in 1972 (pp. 18-20). They assumed (a) average crop of 25 million bushels, (b) a certain level of disposable income, and (c) that all apples sold after February 1 would come from CA. On this basis they came up with a figure of 4.4 million bushels (the 1963 figure was 2.7 million, the 1965 figure nearly 3.1 million). The assumption that all apples after February 1 would come from CA represents, of course, a maximum variant; while it's unlikely to be reached in actual practice, it could be approached.

^{56/} Storage estimates are also prepared by the Statistical Reporting Service of the U. S. Department of Agriculture. Since January 1963, total U. S. CA holdings have been reported monthly in the Cold Storage Report. An estimate of CA capacity by States was first made for October 1, 1963 and repeated for October 1, 1965; it is published in Capacity of Refrigerated Warehouses. The 1965 figures indicated total CA capacity of 14.8 million bu. and holdings of 12.3 million bu. (capacity normally exceeds holdings). The 1963 capacity survey disclosed that 265 storage plants had CA rooms; a similar figure was not tabulated in 1965. The USDA data available as of 1963 are summarized by Ben H. Pubols in "Controlled Atmosphere Storage of Apples," The Fruit Situation, January 1966, pp. 18-21 (reprinted as ERS-276, February 1966).

review IAA data available through the 1965/66 season (preliminary data pertaining to the 1966/67 season may be found in Appendix Tables 3 and 4).

1. Overall Growth

The overall growth in CA holdings on November 1, and the breakdown by States, for the period from 1950 to 1965, is shown in Table 1.^{57/} It will be noted that by 1965, total holdings had reached 12.91 million bushels. About 24.6% of the holdings were in New York State, 21.4% in Washington (see footnote 1 to Table 1), 20.9% in Michigan, 17.0% in New England, and 16.1% elsewhere. Altogether, 17 States were represented. The overall rate of growth has been particularly striking since 1956.

The proportion of total apple storage holdings in CA has climbed steadily over the years. On November 1, 1965, 20.0% of all the apples in storage were in controlled atmosphere. Over the period from 1950 to 1965, total storage holdings on November 1 increased, but it appears that much of the growth was represented by CA storage; regular storage holdings did not change much. (For details on CA and total storage holdings, see Appendix Tables 1 and 2.)

The proportion of total holdings in CA storage, of course, increases through the season. The figures for the 1965/66 season were: November 1, 20.0%; December 1, 23.1%; January 1, 30.7%; February 1, 39.8%; March 1, 49.2%; April 1, 59.2%; May 1, 61.5%; and June 1, 56.0%. This pattern was typical of previous seasons. (For details on storage holdings by months, also see Appendix Tables 1 and 2.)

Apples placed in CA and sold ~~as~~ such, cannot under existing legislation legally be taken out of storage until around the first of the year. The big buildup of stocks in CA rooms takes place by November 1, but increases slightly through January 1, and then begins to decrease as apples move to market. Table 2 indicates first-of-the-month stocks and monthly movement during the 1965/66 season. Clearly, the largest out-of-storage movement took place in March, April, and May.

2. Seasonal Changes by Variety and Region

There are important variations in CA holdings by region and variety through the season.

^{57/} In the IAA data issued during any one season, CA holdings are apt to be slightly higher on December 1 than on November 1. The increase reflects both some filling of rooms during November and late reporting of data from new rooms. Because the latter accounts for the larger share of the difference, subsequent reports are revised by IAA so that the November 1 figure equals the December 1 estimate. In this section the revised "November 1" figures were used in order to facilitate comparison with regular storage holdings (which drop off after November 1). For an earlier analysis using IAA data, see [Dana G. Dalrymple], "Controlled Atmosphere Apple Storage in the United States," International Fruit World (Basle), Summer 1962 (Vol. 21, No. 2), p. 123 ff.

Table 1. U. S. Controlled Atmosphere Storage Holdings by Major Regions or States (in thousands of bushels 1/, November 1)

Year	Total	New York	New England	Michigan	Washington	Others
1950	113.5 2/	113.5	-	-	-	-
1951	206.0 2/	192.5	13.5	-	-	-
1952	252.0	238.5 3/	13.5 3/	-	-	-
1953	392.1	361.1 3/	31.0 3/	-	-	-
1954	530.0	455.2	74.8	-	-	-
1955	814.2	684.1	130.1	-	-	-
1956	949.1	734.4	162.6	30.5	-	21.6 4/
1957	1,728.8	1,129.8	434.2	144.8	-	20.0 4/
1958	3,199.8	1,617.4	862.7	538.1	25.0	156.6 5/
1959	3,950.7	1,769.8	957.8	664.2	142.3	416.6 6/
1960	4,598.0	1,768.4	1,053.0	949.8	473.8	353.1 7/
1961	6,645.7	2,164.3	1,503.7	1,442.4	781.2	754.1 8/
1962	8,491.5	2,375.1	1,707.9	1,759.4	1,698.5	950.5 9/
1963	10,017.6	2,672.9	1,937.8	2,060.0	1,937.9	1,409.0 10/
1964	12,481.1	3,047.2	2,102.4	2,576.0	2,846.8	1,908.6 11/
1965	12,911.6	3,171.3	2,191.8	2,704.6	2,760.2	2,083.7 12/

1/ Washington holdings are reported on a packed box basis; others are on a tree-run basis. This means that Washington holdings are relatively understated, as is -- to a lesser extent -- the U. S. total. Similarly, there is a greater gulf between capacity figures for Washington (as reported by USDA) and reported holdings than is true of other States.

2/ Estimated capacity.

3/ Area breakdown of holdings not reported. Figures were derived by subtracting New England capacity from total holdings.

4/ New Jersey.

5/ New Jersey (50.0), California (56.3), and Oregon (50.4).

6/ New Jersey (94.1), Virginia (12.0), California (262.4), and Oregon (48.1).

7/ New Jersey (93.0), and California (260.1).

8/ New Jersey (117.2), Pennsylvania (10.0), Virginia (11.4), California (565.5), and Oregon (50.0).

9/ New Jersey (98.9), Pennsylvania (40.0), Virginia (25.4), and California (770.2).

10/ New Jersey (216.9), Pennsylvania (240.2), Virginia (177.8), California (697.6), and Oregon (76.5).

11/ New Jersey (304.2), Pennsylvania (373.0), Virginia (373.9), Idaho (63.9), California (733.6), and Oregon (60.1).

12/ New Jersey (241.5), Pennsylvania (371.8), Virginia (355.2), West Virginia (18.0), Illinois (15.8), Idaho (145.4), California (862.2), and Oregon (73.8).

Source: Storage reports of the International Apple Association, except for: (a) 1950-51, estimated by R. M. Smock; (b) 1954-56 area breakdown, unpublished data provided by International Apple Association.

Table 2. Controlled Atmosphere Holdings and Out-of-Storage Movement, 1965/66 Season (in thousands of bushels)

<u>Month</u>	<u>CA Holdings on First of Month</u>	<u>Out-of-Storage Movement During Month</u>
November	12,911.6 bu.1/	-
December	12,911.6	(+ 15.8)
January	12,927.4	554.0 bu.
February	12,373.4	1,768.5
March	10,604.9	2,848.2
April	7,756.7	3,329.9
May	4,426.7	2,836.0
June	1,590.7	1,590.8 2/

1/ See footnote 57, p. 34. The preliminary figure was 12,546,830 bu.

2/ Not all are distributed in June; some may move through the rest of the summer.

CA holdings presented a much larger proportion of total holdings in some areas than others. Consider the breakdown in Table 3 for the four major areas or States at different points during the 1965/66 season. Obviously, CA storage accounted for a relatively higher proportion of total storage holdings in New England than it did in Washington, particularly late in the season. Part of the explanation for this situation is time -- CA storage is much newer in Washington than in New England -- and part is variety. The latter point will be illustrated in the following paragraphs.

Table 3. Controlled Atmosphere Holdings as a Proportion of Total Holdings by Region, 1965/66 Season

<u>Area</u>	<u>November 1</u>	<u>March 1</u>
New England	44.2%	90.0%
New York	31.7	72.7
Michigan	33.6	82.8
Washington 1/	13.5	29.2
United States	20.0%	49.2%

1/ Packed box basis (see footnote 1, Table 1).

There is a considerable variation in CA holdings by variety. In terms of total CA holdings, the most important varieties on November 1, 1965, were

McIntosh (35.2%) and Red Delicious (29.7%), followed by Jonathan (10.5%), Newtown (6.5%), Rome (6.6%), Golden Delicious (3.6%), Stayman (2.4%), and Northern Spy (1.5%). The breakdown in 1965 was quite different from what it was in 1960 and 1956. As was indicated earlier, CA storage basically started around the McIntosh variety; in the ensuing years it has spread to others. Thus McIntosh has decreased in relative importance: in 1956, it accounted for 84.1% of holdings; in 1960, 60%. Conversely, Red Delicious increased from 8.2 to 16.5%, Jonathan from 0 to 8.8%, and Newtown from 0 to 5.7%.

Another way to consider the variety situation is to look at CA holdings of a specific variety as a proportion of total storage holdings of that variety at different points in the season. This is illustrated for the 1965/66 season in Table 4. From this data we can see that CA storage was of great importance to McIntosh, Jonathan, and Newtown varieties, both on November 1 and on March 1. Red Delicious and Rome were near the average figure for all varieties. Just how high these proportions will go in future years is a moot point.^{58/}

Table 4. Proportion of Total Variety Holdings in Controlled Atmosphere,
1956/66 Season

<u>Variety</u>	<u>November 1</u>	<u>March 1</u>
McIntosh	51.4%	89.6%
Red Delicious	20.7	51.6
Jonathan	43.1	87.8
Newtown	38.2	78.6
Rome	19.8	51.7
Golden Delicious	8.2	28.4
Stayman	13.1	42.5
Northern Spy	15.8	50.1

Other Varieties	3.6	9.6
Not Segregated	0.9	2.8

All Varieties	20.0%	49.2%

^{58/} But possibly an upper limit can be estimated for all varieties. Under existing legislation a CA room generally cannot open until mid-January to mid-February at the earliest. Over the 16-year period from 1950-51 to 1965-66, slightly over 49% of the apples in all storage on November 1 were moved out after February 1 (this figure has not tended to increase). So perhaps the maximum figure for CA holdings of all varieties as a proportion of all November 1 holdings might be about 50%. The process is admittedly rough -- and is even more so when applied to individual varieties for reasons which will become evident in Section 3.

Having reviewed CA holdings from first a regional, and then a varietal point of view, we can now analyze them in combined form. Calculation of variety breakdown by the four leading areas reveals that on November 1, 1965: about 85% of the McIntosh in CA were held in New York and New England, nearly 66% of the Red Delicious were in Washington, almost 99% of the Jonathan were in Michigan, 94% of the Newtowns were in California, and 61% of the Northern Spys were in Michigan. Distribution of the other varieties was somewhat less concentrated. Another approach is to consider the breakdown within each of the four areas. This process reveals that on November 1, 1965: in New England, 87% of the apples in CA were McIntosh; in New York, 62% were McIntosh; in Michigan, 49% were Jonathan; and in Washington, 91% were Red Delicious.

All of this is to show that there is a considerable variation in variety holdings by regions or States.

3. Effect on Total Storage Pattern

Now it may be worthwhile to step back and see what changes have taken place in total storage holding patterns (that is, in holdings of both regular and CA apples) during the period from 1950 to 1965. We have noted that there has been an overall expansion in apples stored and that much of this was due to increased CA storage.

Has the expansion in CA been associated with any significant change in the quantity stored when the increasing apple production of the period is taken into account? The data in Table 5 indicate that proportion of apple production in all storages as of four points during the 16-year period.

Table 5. Average Proportion of Total Apple Production in Storage

Season	Proportion in Storage on			
	Nov. 1	Jan. 1	March 1	May 1
1950/51 - 1954/55	42.5%	29.9%	15.5%	4.7%
1955/56 - 1959/60	46.1	30.7	15.3	4.4
1960/61 - 1964/65	47.0	30.5	15.6	5.1
1965/66	47.4	31.0	15.8	5.3
Average	45.4%	30.4%	15.5%	4.8%

It may be seen that the proportion in storage on the first of the month increased somewhat over time. The increase, however, was most noticeable on November 1. On January 1 and March 1, there was little change. By May 1, a slight increase began to become evident. Thus, it appears that the change in overall proportion of the crop stored later in the season may have been less than some of the preceding material might have suggested. With increasing crops, more storage space was needed, and CA was built to

some extent in the place of regular storage. Consequently, even with more CA, the total proportion of the crop held in storage did not begin to increase very perceptibly until after March 1.

But if the quantitative changes were not very great, the qualitative ones were. As the varietal composition of apple production changed over the period from 1950 to 1965, there ~~was~~ a change in the types of varieties put in storage. The proportion of total holdings on November 1 by variety changed as follows from 1950 to 1965:59/

Increases of more than 2%: Red Delicious, from 23.5% of all varieties to 28.7%; McIntosh, from 10.9 to 13.7%; Golden Delicious, from 1.6 to 8.7%; Jonathan, from 1.5 to 4.9%; York, from 1.8 to 4.6%; Stayman, from 1.6 to 3.7%. (Rome, from 5.9 to 6.7%).

Decreases of more than 2%: Winesap, from 18.1 to 6.7%

These changes in holdings roughly followed those in production.^{60/} The increase in storage holdings of Red Delicious and Jonathan, however, was about double the change in production.

And while there has been a change in composition early in the storage season, the situation is even more pronounced for some varieties by March. To follow the above system, the proportion of apples in storage on March 1 changed as follows from 1950 to 1965:

Increases of more than 2%: Red Delicious, from 21.1% of all varieties to 33.3%; McIntosh, from 8.8 to 20.3%; Golden Delicious, from 1.1 to 7.0%; Jonathan, from 0.7 to 4.4%; York, from 1.0 to 3.5%. (Rome, from 5.5 to 7.1%).

Decreases of more than 2%: Winesap, from 27.7 to 12.3%; Newtown, from 6.8 to 4.7%; and Baldwin, from 2.7 to 0.6%.

Compared with November holdings, the biggest net increase in March holdings from 1950 to 1965 was registered by McIntosh, followed by Red Delicious, Rome, and Jonathan. The sharpest decrease was made by Winesap, with lesser decreases made by Baldwin and R. I. Greening.

59/ The comparison here is between the two years. However, data were also computed for 1955 and 1960 to see if the trend was consistent in those years. It was in each case, except for McIntosh where the proportions were 14.2 and 14.8% respectively. Changes of more than 2% were arbitrarily chosen to allow for the fact that there was an increase in the proportion of holdings by variety reported during the period.

60/ An exception was provided by York: relative production declined while storage holdings increased. The explanation is that there was a sharp increase in the quantities held for processing.

It is, of course, evident that the varieties which are increasing in relative importance in storage, particularly late in the season, are those which are held in quantity in CA storage; and the varieties which are decreasing are, except for Newtown, those which are not generally placed in CA. This is not accidental. Several of the varieties increasing in importance, such as McIntosh and Jonathan, formerly could not be held for long periods because of low temperature injury; other varieties such as Red Delicious did not have this problem but benefited from CA storage. On the other hand, the primary virtue of Winesap and Baldwin was their long keeping ability under regular storage rather than their fresh eating qualities; for them CA storage offered no significant improvement.61/

* * *

In summary, we have seen that the impact of CA storage on the total storage picture has been more qualitative than quantitative. What CA storage has done is not so much to increase the total proportion of the crop stored as it has been to accommodate -- and perhaps stimulate -- an increase in production and a change in varietal composition. Varieties which were formerly stored primarily for their keeping, rather than eating, qualities have been replaced by varieties that formerly could not be held so well for long periods, but which have preferred eating qualities. And these higher quality varieties are being held much later in the season in much better condition.

61/ Another possible reason for decreased holdings centers about the fact that varieties like Baldwin are often considered "cooking" varieties. They are purchased fresh in part for cooking in the home. Home cooking of this nature appears to be on the decrease (Dalrymple and Feustel, op. cit. (1965), p. 17).

V. PROGRESS IN OTHER AREAS

In this section, we broaden our view to consider: (A) recent commercial developments in the use of CA for other fruits in the U. S., (B) the general status of CA storage in other countries, and (C) some additional uses for CA and possible new areas of investigation.

A. Other Fruits

Although CA storage has found its main application in the U. S. with apples, interest continues in applying it to other fruits. The advent of mechanical generators has led to studies on a number of different products. It is beyond the scope of this paper to try to review all the research projects.^{1/} Rather, we will try to cover a few of the highlights concerning commercial experience as reported in the trade press and note several recent Department of Agriculture reports.^{2/}

Pears. It has been well known for some time that pears respond well to CA storage. From time to time pears have apparently been stored in CA in Oregon, but evidently not in a systematic matter. During the 1964/65 season, 14,600 bu. of Bartletts for processing were "successfully" held under a generator for five months in Michigan.^{3/} Tests were broadened to include Bartletts for both fresh and processing markets during the 1966/67 season.^{4/} A generator was also to be used for pears in British Columbia during the 1966/67 season.^{5/}

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- 1/ The paper by Hardenburg and the USDA card file cited earlier (Chp. IV, fn. 1) provided biographical information covering a wide range of horticultural crops. Similar data may be found in W. Hugh Smith, "The Use of Carbon Dioxide in the Transport and Storage of Fruits and Vegetables," Advances in Food Research, Academic Press, 1963 (Vol. 12), pp. 138-146. As of the end of 1966, the horticultural departments at the University of California, Davis, were in the process of compiling a comprehensive bibliography.
- 2/ The trade press accounts generally refer to the initiation of commercial trials. They should not, of course, be viewed in the same light as research reports.
- 3/ "Pears Held Successfully in CA Storage," The Great Lakes Fruit Growers News, March 1965, p. 1.
- 4/ "Some Changes in Personnel for Tectrol," The Packer, September 27, 1966, p. 15.
- 5/ Letter from W. Paul Jensen, Atlantic Research Corporation, September 24, 1966.

Peaches and Nectarines. Two chain stores operating in the Northwest were cited as holding peaches for their own use under generators during the fall of 1966.^{6/} Favorable results on holding peaches were reported by U. S. Department of Agriculture researchers in August 1966. They tested Redheaven and Sunhigh peaches and Le Grand nectarines.^{7/}

Apricots. A California storage operator stated in 1964 that he had held mechanically harvested apricots in CA storage for long periods with good results.^{8/}

Sweet Cherries. Two Michigan growers held cherries in their apple storages under generators during the summer of 1964; in one case the size of the lot was about 30 tons. The growers indicated that the cherries held up relatively well for six weeks. The main problem was that neither grower had a sufficiently highly developed fresh market to absorb them and two-thirds ended up being sold at lower prices for processing.^{9/} A U. S. Department of Agriculture study on sweet cherries released in 1964 reported beneficial effects from CA storage.^{10/}

Strawberries. During the summer of 1966, a Michigan grower kept strawberries for ten days in his apple storage under a mechanical generator. Some 250 cases were stored and reportedly probably could have been held longer.^{11/}

Oranges. In early 1965, it was announced that Sunkist in California was going to initiate a large-scale test on oranges. At least 100,000 cartons were to be involved. Apparently small-scale tests had been underway for over two years.^{12/} No report on the project has yet been noted.

6/ "Some Changes...," op. cit.

7/ "Controlled Atmospheres Tested by USDA for Peaches, Nectarines," U. S. Department of Agriculture, news release 2645-66, August 17, 1966. (Reported in Western Fruit Grower, October 1966, p. 28.)

8/ "Modified Atmospheres, A Panacea for Produce?," Western Grower and Shipper, May 1964, p. 9.

9/ "Cherries Held Successful in CA Storage," The Great Lakes Fruit Growers News, April 1965, p. 1.

10/ Harold A. Schomer and Kenneth L. Olson, Storage of Sweet Cherries in Controlled Atmosphere, U. S. Department of Agriculture, Agricultural Marketing Service, AMS-529, April 1964, 7 pp.

11/ "Shafer Lake Holds Strawberries Ten Days in Tectrol," The Great Lakes Fruit Growers News, August 1966.

12/ "Sunkist Plans Thorough Test of Controlled Atmosphere Storage," The Packer, March 6, 1965, p. 12.

Oranges and Grapefruit. Shortly after Sunkist's announcement, the Florida Citrus Commission authorized its commercial development department to investigate the feasibility of storing oranges and grapefruit in cooperation with a commercial grove. The fruit was to be shipped to Boston and evidently held in an apple storage after the season was over. It was planned to hold the fruit for eight to ten weeks.^{13/} Again, no report on the project has been noted.

Grapefruit. A different set of tests with grapefruit was subsequently reported by the Florida Citrus Exchange in cooperation with one of the generator manufacturers. Grapefruit were reportedly held successfully for two months. At the same time it was noted that over 50 cars of citrus were being held around the country in apple storages which had completed operations for the season.^{14/} Studies on grapefruit were initiated by the U. S. Department of Agriculture in 1957.^{15/}

Other. The U. S. Department of Agriculture has reported research on a number of other fruits. Included are: lemons,^{16/} plums, grapes, and strawberries.^{17/} Further work is in progress, including studies on avocados.

Hardenburg suggests that the widespread use of polyethylene box liners for pears and sweet cherries may help account for relatively limited commercial

^{13/} "Florida Citrus Commission Will Try CA Storage of Citrus Fruit," The Packer, May 1, 1965, p. 31.

^{14/} "Research Shows Grapefruit Can be Stored Longer Time," The Produce News, June 19, 1965, p. 3.

^{15/} E. W. Scholz, H. B. Johnson, and W. R. Buford, Storage of Texas Red Grapefruit in Modified Atmospheres, A Progress Report, U. S. Department of Agriculture, Agricultural Marketing Service, AMS-414, October 1960, 11 pp.

^{16/} C. L. Rugg and A. W. Wells, Experimental Storage of California Lemons in Controlled Atmospheres, U. S. Department of Agriculture, Agricultural Marketing Service, AMS-475, May 1962, 11 pp.

^{17/} See the following articles in the Proceedings of the American Society for Horticultural Science: H. Melvin Covey, "Effects of Temperature and Modified Atmosphere on the Storage Life, Ripening Behavior, and Dessert Quality of Eldorado Plums," 1960 (Vol. 75), pp. 207-215; H. Melvin Covey, "Modified Atmosphere Storage of Nubiana Plums," 1965 (Vol. 86), pp. 166-168; M. Uota, "Preliminary Study on Storage of Emperor Grapes in Controlled Atmospheres With and Without Sulfur Dioxide Fumigation," 1957 (Vol. 69), pp. 250-253; R. E. Anderson, R. E. Hardenburg, and H. C. Vaught, "Controlled-Atmosphere Storage Studies with Cranberries," 1963 (Vol. 83), pp. 416-422.

CA storage of these two fruits. The plastic liners cause a modified atmosphere to be formed in each container.^{18/}

In the application of controlled atmospheres to fruits other than apples, the mechanical generators may well play a significant role. This is because of the ability of the generators to arrive quickly at a desired atmosphere, an important factor in holding items with a higher respiration rate and shorter storage life than apples.

B. Other Countries

During the period since World War II, there has been a continued expansion of interest in controlled atmosphere storage throughout the world. This interest is shown in terms of both research and commercial activity.

The increase in research has, in fact, been so great that it would be well beyond the scope of this paper to begin to review it. Instead, the interested reader is directed to several other sources. The first is composed of the review of literature and bibliographies which have already been footnoted.^{19/} The second source is composed of two recent papers by Dr. J. C. Fidler of the Ditton Laboratory in England.^{20/}

In this section, we will turn more to a review of the general situation with respect to commercial use of CA. All estimates apply to mid-1966 and to apples unless otherwise noted. Canada, as noted earlier, has had a long history of research on controlled atmosphere. As of November 1, 1965, total CA holdings reached about 2.6 million bushels, nearly 22% of all apples in storage. The biggest portion of Canadian holdings ~~was~~ found in

^{18/} Letter from R. E. Hardenburg, Market Quality Research Division, U. S. Department of Agriculture, November 15, 1966. Detailed discussion of the use of film liners is outside the scope of this report. The interested reader is directed to the following reports published by the U. S. Department of Agriculture: Fisk Gerhardt, Use of Film Box Liners to Extend Storage Life of Pears and Apples, Circular 965, April 1955, 28 pp.; Fisk Gerhardt, Harold Schromer, and T. R. Wright, Sealed Film Lug Liners for Packing Bing Cherries, AMS-121, September 1956, 8 pp.

^{19/} See: Chapter IV, footnote 1 (p. 19); Chapter V, footnote 1 (p. 41).

^{20/} J. C. Fidler, "Controlled Atmosphere Storage of Apples," The Journal of Refrigeration, London, August 1965 (Vol. 8, No. 8), pp. 265-273 (to appear in the Proceedings of the Institute of Refrigeration, London, in press); John C. Fidler and Basil G. Wilkinson, "Controlled Atmospheres as a Means of Extending the Life of Horticultural Produce," Proceedings of the XVII International Horticultural Congress, East Lansing, 1967, in press.

Quebec (44%), followed by Ontario (38%), British Columbia (14%), and the Maritimes (5%).^{21/} Generators are used in a number of storages.

Although the United Kingdom has the longest experience with CA, apparently there is no systematic reporting procedure. Dr. Fidler estimated that the total for the country was about 175,000 tons, about half of which was in Kent.^{22/} A rough conversion suggests that the total may have been around 8.7 million bushels.

Estimates for other European nations have been gathered by the International Apple Association.^{23/} As the figures usually were reported in metric tons, a conversion has been made to 45 lb. bushels.^{24/}

Netherlands. The IAA reporter indicated a total of 40,000 tons or nearly 2 million bu. About 90% of this space was used for apples and 10% for pears. Estimated capacity for 1967 is 50,000 tons or nearly 2.5 million bu.

Germany. IAA reports suggested holdings of about 7,500 tons or about 368,000 bu. An additional 5,000 tons or 245,000 bu. were expected to be added in 1966.

Switzerland. The IAA indicated about 12,500 tons capacity, of which only about 7,000 were actually used. The latter figure is equivalent to about 343,000 bu.

France. There was some variation in estimates. The IAA reporter suggested that capacity was negligible in the spring but that it would total about 1 million bu. by the fall. Another French source indicated a figure of about 5,000 tons (245,000 bu.) in February.^{25/} And a representative of the French Ministry of Agriculture placed the total for the end of 1965 in between the previous two estimates.^{26/}

^{21/} Based on the November 1, 1965, storage report issued by the International Apple Association.

^{22/} Letter from Dr. Fidler, September 6, 1966.

^{23/} "IAA Special Letter;" No. 35, June 3, 1966; No. 45, July 8, 1966.

^{24/} IAA conversion figures were used: 49 bu. per metric ton, 49.8 bu. per long ton.

^{25/} Based on an estimate given by a speaker at a marketing meeting in Avignon and reported in "Weekly Deciduous Information," April 20, 1966 (issued by the Fruit and Vegetable Division of the Foreign Agricultural Service, U. S. Department of Agriculture).

^{26/} G. Maurel, "Le Développement en France des Chambres à Atmosphère Contrôlée Pour la Conservation des Pommes," Annexe 1, Bulletin of (cont.)

Italy. The IAA source estimated 80,700 metric tons or nearly 4 million bu. This was distributed about as follows: South Tyrol 65%, Verona 25%,^{27/} and Emilia Romagna 10%.

In other countries, the situation is mixed. Fidler reported that Israel had a capacity of 10,000 tons (long) with 5,000 under construction; total capacity would be equal to almost 750,000 bu.^{28/} In the British Commonwealth: Australia had no more than a half-dozen commercial CA rooms;^{29/} New Zealand had plans for holding a "commercial quantity" during the 1967 storage year;^{30/} and South Africa had no CA rooms in operation but there was some interest for Delicious.^{31/} Japan had CA capacity of around 150,000 bu.; additional construction is anticipated.^{32/}

Nearly all of the CA storage outside of America -- except Canada -- has been the traditional or product-generating type. The use of externally generated systems is relatively limited to date. Fidler thinks that European storages are likely to remain the product-generated type: "This is because it is generally considered that very large chambers are uneconomic ... and also because the respiration of European varieties at the temperature of storage (38-40°F) is sufficiently active to produce the desired gas concentrations rapidly." He thinks that the external systems are not apt to play an important role in holding produce with "a

(cont.) International Institute of Refrigeration, Paris, 1966, pp. 215-218. Maurel reports a capacity of 50 to 60,000 cubic meters.

27/ For details on the development of CA storage in this area, see D. Rui and P. Mori, "Developpement et Résultats de la Conservation en Atmosphère Contrôlée en Vénétie," Annexe 1, Bulletin of the International Institute of Refrigeration, Paris, 1966, pp. 209-214.

28/ This information was obtained from A. Sieve of the Israel Fruit Growers Association.

29/ Letter from E. G. Hall, Fruit Storage Section, Division of Food Preservation, Commonwealth Scientific and Industrial Research Organization, Rye, N. S. W., September 23, 1966.

30/ Letter from C. S. Padfield, Fruit Research Orchard, Department of Scientific and Industrial Research, Havelock North, September 26, 1966. Padfield reports that interest has been sporadic.

31/ Letter from L. Ginsburg, Cold Storage and Transport Section, Fruit and Food Technology Research Institute, Department of Agricultural Technical Service, Stellenbosch, September 9, 1966.

32/ Based on letters from: Hideo Mori, Horticultural Research Station, Ministry of Agriculture and Forestry, Shimokuriyagawa, Morioka, November 29, 1966; and Shigenori Aikawa, Research and Development Department, C. Itoh & Co., Ltd., Tokyo, November 28, 1966 (the storages are almost evenly divided between four Prefectures).

short potential storage life, and for which the 'pull-down' period would represent too great a proportion of the storage and distribution time."33/

The outcome remains to be seen. In April 1966, Tectrol announced that it had signed agreements with companies in Japan "for use of Tectrol systems for storing apples and for research aimed at Tectrol storage of other crops." Subsequently, a field test on apples was successfully completed in Australia and arrangements were made for field tests in Italy.^{34/} And the Arcagen system will be used in Mexico and Israel during the 1966/67 season.^{35/}

C. Other Uses and Technologies

CA storage is in a dynamic stage of development. New uses and new technologies are constantly being evolved. In this section we will briefly note several of these developments. Others will probably be quick to follow.

1. Expanded Uses

Mechanical generators hold promise of extending the CA concept beyond stationary storage and into transportation units and distribution warehouses.^{36/}

Whirlpool Corporation has formed a subsidiary company known as TransFresh Inc. to work on transportation applications. Much of the work of TransFresh has centered about fresh vegetables, especially lettuce. The procedure is to manufacture the atmosphere outside the trailer and then to inject it into the loaded area. The trailers are modified to make them air tight. Special containers are used for weekly boat shipments of California fruits and vegetables between the mainland and Hawaii.^{37/}

33/ Fidler, op. cit. (1967; Horticultural Congress).

34/ "Announce Big Volume In New Tectrol Systems," The Packer, April 16, 1966 p. 13; letters from Richard Sawyer, Tectrol Division, Whirlpool Corporation, October 7, 28, 1966.

35/ Letter from W. Paul Jensen, Atlantic Research Corporation, September 27, 1966.

36/ As we noted earlier (p. 16), much of the early USDA work in CA was directed at pre-transport treatments. For a general discussion of the matters reviewed in this section, see Harold Rogers, "Good Is Not Good Enough," Produce Marketing, October 1966, pp. 61-66.

37/ "Tectrol by the Trailer Loads," Produce Marketing, May 1966, pp. 54-55; "... Billing on Tectrol Atmosphere Shipments," The Packer, October 1, 1966, p. 8; "Tectrol Curbs Lettuce Arrival Condition Ills." The Produce News, November 19, 1966, p. 8; letter from James Lugg, TransFresh (Salinas, Calif.), October 12, 1966.

Several other transportation systems are also available. One is the "Polarstream" process manufactured by the Linde Division of Union Carbide. Another is the "Oxytrol" system developed by the Best Fertilizer Division of the Occidental Petroleum Corporation. Both involve the use of nitrogen. In the Polarstream process, liquid nitrogen is released, serving both as a refrigerant and to help keep oxygen at a low level. The Oxytrol process uses nitrogen only for atmosphere control. In either case, modification of rail and truck equipment is necessary.^{38/} The Market Quality Research Division of the U. S. Department of Agriculture has conducted a number of studies on the tolerance of produce to high nitrogen.^{39/}

Tectrol is now giving emphasis to developing installations in distribution warehouses, terminal wholesalers, tomato repackers, etc. Ultimately, they hope to move on to retail stores and finally get back to the home refrigerator market -- the one they started out for in the first place. In May 1966, they held a press conference to show drawings of proposed units.^{40/}

2. New Technologies

Several new technologies are under study which may in time have influence on CA storage.

A strikingly simple method of maintaining desired atmospheres for apples has been reported by two French researchers, P. Marcellin and J. Leteinturier. Their system involves automatic atmosphere control by diffusion through a silicone rubber "exchanger-diffuser." Laboratory research was reported in 1964, and a commercial-size installation was built in Montfrin (Gard) in 1965. According to the researchers:

38/ "New Transit Services Offered," Produce Marketing, May 1966, pp. 22, 25, 26. The Polarstream process is also outlined in a brochure, Polarstream Refrigeration, issued by the company. Oxytrol is discussed by D. A. Dixon in "A User's Experience With Liquid Nitrogen," International Conference on Handling Perishable Agricultural Commodities (Purdue University), March 1966, pp. 112-123.

39/ C. S. Parsons, J. E. Gates and D. H. Spalding, "Quality of Some Fruits and Vegetables after Holding in Nitrogen Atmospheres," Proceedings of the American Society for Horticultural Science, 1964 (Vol. 84), pp. 549-556; John M. Harvey, "Nitrogen - Its Strategic Role in Produce Freshness," Produce Marketing, July 1965, pp. 17-18; John M. Harvey, "Modified Atmospheres in Transport," 1966 Yearbook, United Fresh Fruit and Vegetable Association, pp. 193-194.

40/ "Tectrol by...," op. cit.; letter from Don Ranum, Tectrol Division, Whirlpool Corporation, September 14, 1966; "Controlled Atmosphere Could Help Housewife Keep Food Fresh at Home," The Packer, October 8, 1966, p. 24.

The exchanger-diffuser will handle 250 tons of apples and makes use of the special properties of these silicone rubbers used for gas diffusion and automatically maintains the required gas composition at all times, i.e., 3% oxygen, 3% carbon dioxide and 94% nitrogen. This unit is simple to operate, it consumes no material and requires very little energy. Operation of the installation during the 1965-1966 season proved very easy, the only supervision being regular analysis of the gas mixtures.

Golden Delicious were stored. The room was closed in late October and opened in early May, for a total storage period of 185 days.^{41/} Further study is presumably underway.

A radically different process has recently undergone laboratory testing in Florida and appears promising. Two researchers at the University of Miami have reported that introduction of partial vacuums markedly delayed ripening of tropical fruits. The effect was thought to be due to oxygen depletion and the acceleration of the escape of the ripening hormone ethylene from the fruit tissue. Also, the partial vacuum lowered the fruit's sensitivity to ethylene by reducing oxygen tension. The research was centered about bananas, but also included tomatoes, avocados, mangos, Florida sweet cherries, limes, and guavas. Relatively small quantities of fruit were used.^{42/} Further testing would seem to be in order.

^{41/} P. Marcellin and J. Leteinturier, "Étude d'une Installation de Conservation de Pommes en Atmosphères Contrôlées," Annexe 1, Bulletin of the International Institute of Refrigeration, Paris, 1966, pp. 141-152.

^{42/} Stanley P. Burg and Ellen A. Burg, "Fruit Storage at Subatmospheric Pressures," Science, July 15, 1966 (Vol. 153, No. 3733), pp. 314-315. (The work was supported by a grant from the United Fruit Co.)

VI. CONCLUDING REMARKS

Controlled atmosphere storage of apples has been a remarkable success story. Although the basic concept has been around for many years, it was not until the 1920's in England and 1930's in the United States that research ~~was~~ initiated on a systematic basis. Commercial expansion in apple storage got underway in the 30's in England and in the 40's in the United States. About 20% of the apples placed in storage in the U. S. in 1965 were in CA. This process has brought about greater returns to the grower and higher quality to the consumer. The recent development of mechanical generating units has increased interest in using the process for other fruits and at other stages in the marketing process. Just how commercially successful these other applications will be remains to be seen.

The use of controlled atmospheres provides a notable example of the commercial implementation of scientific knowledge. The concept originated in the laboratory and was the subject of years of scientific study. When a sound scientific base of information was accumulated, the process was taken out for preliminary commercial trial in apple storage. The trials were conducted with the assistance of the same scientists who carried out the laboratory work. As the process proved successful, commercial use expanded. The subsequent value of CA storage to the apple industry cannot be precisely estimated, but it is certainly well in the millions of dollars.

The key individuals in this process were, as we have seen, Drs. Kidd and West in England and Smock in the United States. All three followed the process from infancy to commercial reality in their respective countries. Smock has now spent 30 years on CA storage, among numerous other projects. Not only did he carry out the initial research in New York, but he helped get the first commercial storages underway, and has worked closely with the industry on its problems ever since. Moreover, many of those who subsequently initiated research in other States were former students of his. Dr. Smock's contributions to the apple industry have been well known to growers: in 1958, he was presented a special "Award of Merit" by the New York State Horticultural Society;^{1/} in 1966, he received the National Apple Institute's award for "Outstanding Contributions to Apple Marketing."^{2/} Dr. Van Doren, Smock's associate in the early years at Cornell, was honored by the Washington apple industry in 1966.^{3/} (Smock and

1/ "Dr. Smock Presented Award of Merit," Proceedings of the One Hundred and Third Annual Meeting of the New York State Horticultural Society, 1958, p. 194.

2/ "Dr. Robert Smock Given NAI's Annual Award for Aid to Apple Marketing," The Produce News, June 25, 1966, p. 9.

3/ "Wash. State Apple Leaders Honor Dr. Archie Van Doren As Pioneer in CA Storage," The Produce News, March 26, 1966, p. 8.

Van Doren's predecessors, Kidd and West, were awarded the Kammerligh Onnes gold medals of the Netherlands Refrigeration Association in 1963.)^{4/}

The work of these leaders, and others, was done at public institutions. In England the research was sponsored by the central government; in the U. S. the research was mainly conducted at the State colleges of agriculture. Commercial firms were not heavily involved through the late 1950's. But then, there was nothing about the process that seemed to make it worthwhile for one firm to do much broad-scale research. There was no single key physical product to be sold: the process utilized a variety of ordinary products, such as metal sheeting, which were available from any number of sources.

But with the expansion of CA storage, several non-agricultural firms saw the possibilities for mechanical generators. The concerns subsequently invested very substantial sums in developing and testing generators. They had the financial and technical resources to do so; the public institutions did not. But even at this stage, the public institutions have been conducting research with the generators, providing unbiased test results, and suggesting modifications and new applications. There has been, in short, a fortunate balance between public and private activity.

In total, then, the development of controlled atmosphere storage of fruit to its present stage provides a striking case of the flow of publicly supported research into commercial use, to the benefit of all groups involved.

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4/ Letter from J. C. Fidler, Ditton Laboratory, U. K., October 25, 1966.

VI. APPENDIX

Selected References

This very brief listing includes a few of the references cited in the report which may be of special interest. Not all the publications are readily available (several of the bulletins are out of print).

A. Early Research

Franklin Kidd, Cyril West, and N. A. Kidd, Gas Storage of Fruit, Department of Scientific and Industrial Research (U.K.), Food Investigation Special Report No. 30, 1927, 87 pp.

R. M. Smock and A. Van Doren, Controlled-Atmosphere Storage of Apples, Cornell University, Agricultural Experiment Station, Bulletin 762, June 1941, 45 pp.

B. General Technical

R. M. Smock, Controlled Atmosphere Storage of Apples, Cornell University, Extension Bulletin 759, May 1958, 35 pp.

New York-New England Controlled Atmosphere Storage Seminar Proceedings, Cornell University, Department of Pomology, 1966, 84 pp. (\$1.00).

J. C. Fidler, "Controlled Atmosphere Storage of Apples," The Journal of Refrigeration (London), August 1965 (Vol. 8, No. 8), pp. 265-273 (to appear in the Proceedings of the Institute of Refrigeration, London, in press).

C. General Economic

Dana G. Dalrymple, Marketing Controlled Atmosphere Apples, Cornell University, Department of Agricultural Economics, A.E. 1028, June 1956, 59 pp.

Ben H. Pubols, "Controlled Atmosphere Storage of Apples," The Fruit Situation (U. S. Department of Agriculture, Economic Research Service), January 1966, pp. 18-21. Also issued separately as ERS-276, February 1966.

D. Technical Bibliographies

W. Hugh Smith, "The Use of Carbon Dioxide in the Transport and Storage of Fruits and Vegetables," Advances in Food Research, Academic Press, 1963 (Vol. 12), pp. 138-146.

A Review of Literature on Harvesting, Handling, Storage and Transportation of Apples, U. S. Department of Agriculture, Agricultural Research Service, ARS 51-4, August 1965, pp. 85-102.

Table 1. U. S. Controlled Atmosphere Storage Holdings of Apples
(first of month, thousands of bushels)

<u>Crop Year</u>	<u>November^{1/}</u>	<u>December</u>	<u>January</u>	<u>February</u>	<u>March</u>	<u>April</u>	<u>May</u>	<u>June</u>
1955/56	814	815	815	815	814	665	385	64
1956/57	958	958	958	958	901	686	273	-
1957/58	1,729	1,729	1,729	1,729	1,695	1,298	553	12
1958/59	3,200	3,200	3,200	3,159	3,137	2,735	1,729	695
1959/60	3,951	3,951	3,951	3,851	3,308	2,212	987	262
1960/61	4,598	4,560	4,426	3,828	2,472	1,241	325	
1961/62	6,646	6,631	6,540	6,042	4,226	2,404	778	
1962/63	8,491	8,515	8,294	7,300	5,392	3,168	1,009	
1963/64	10,018	9,948	9,433	8,221	5,941	3,296	1,018	
1964/65	12,481	12,476	11,782	10,334	7,580	4,462	1,623	
1965/66	12,912	12,912	12,927	12,373	10,605	7,757	4,427	1,591

1/ See footnote 57, p. 34.

Source: Monthly Storage Reports of the International Apple Association.

Table 2. U. S. Total Storage Holdings of Apples
(first of month, thousands of bushels)

<u>Crop Year</u>	<u>November</u>	<u>December</u>	<u>January</u>	<u>February</u>	<u>March</u>	<u>April</u>	<u>May</u>	<u>June</u>
1955/56	51,352	45,017	34,489	25,723	17,696	10,509	5,090	1,660
1956/57	45,123	39,156	30,064	21,215	13,836	7,754	3,578	1,184
1957/58	59,008	50,391	39,037	27,819	18,494	9,728	4,335	1,304
1958/59	58,313	50,734	39,547	29,986	21,855	14,599	8,197	4,077
1959/60	53,959	46,754	34,972	25,428	17,401	9,709	4,569	1,280
1960/61	49,003	40,281	30,619	22,729	15,897	9,393	4,719	1,741
1961/62	56,591	49,906	37,726	26,907	18,596	10,824	5,798	2,112
1962/63	58,645	48,110	37,509	27,438	18,980	11,839	6,268	2,142
1963/64	65,158	53,872	42,069	31,021	21,290	12,598	6,601	2,726
1964/65	65,135	55,903	43,122	32,623	23,568	15,035	8,953	4,046
1965/66	64,526	55,960	42,172	31,069	21,538	13,103	7,193	2,843

Source: Monthly Storage Reports of the International Apple Association.

Table 3. U. S. Controlled Atmosphere and Total Storage Holdings of Apples by Major States or Regions (November 1, 1966, thousands of bushels)1/

	<u>Controlled Atmosphere 2/</u>	<u>Total</u>
Washington 3/	3,779 bu.	27,221 bu.
New York	2,937	8,967
Michigan	2,595	7,555
New England	2,084	4,205
California	879	3,190
Pennsylvania	267	2,615
New Jersey	251	760
Idaho	190	552
Virginia	157	1,926
Oregon 3/	31	2,369
West Virginia	19	914
Illinois	18	319

Others	-	2,923
United States	13,206 bu.	63,516 bu.

- 1/ Total apple production in 1966 was estimated by the USDA (on December 1) as nearly 130 million bushels, down almost 5% from 1965. Changes in production by State or region, compared with 1965, were: Washington, +32.0%; New York, 0; Michigan, 0; New England, -16.1%; California, +42.0%; Pennsylvania, -25.2%; New Jersey, -18.5%; Idaho, -14.3%; Virginia, -55.2%; Oregon, +7.3%; West Virginia, -48.0%; and Illinois, -18.0%.
- 2/ Revised estimate issued in December (see fn. 57, p. 34). (Canadian holdings totaled 2.4 million bu.)
- 3/ Reported on a packed box basis.

Source: Storage reports of the International Apple Association (issued November 14 and December 10, 1966).

Table 4. U. S. Controlled Atmosphere and Total Storage Holdings of Apples by Major Varieties (November 1, 1966, thousands of bushels)^{1/}

	<u>Controlled Atmosphere</u> ^{2/}	<u>Total</u>
Red Delicious	4,827 bu.	20,213 bu.
McIntosh	4,022	7,310
Jonathan	1,226	2,770
Rome	877	3,807
Newtown	697	3,284
Golden Delicious	630	6,619
Stayman	196	1,137
Northern Spy	188	1,349

Other Varieties	460	11,963
Not Segregated	84	5,065
All Varieties	13,206 bu.	63,516 bu.

- ^{1/} Total apple production in 1966 was estimated by the USDA (on December 1) as nearly 130 million bushels, down almost 5% from 1965. Changes in production by variety, compared with 1965, were: Red Delicious, +3.0%; McIntosh, -7.7%; Jonathan, -8.5%; Rome, -9.5%; Newtown, -4.8%; Golden Delicious, +6.5%; Stayman, -47.4%; and Northern Spy, -6.1%.
- ^{2/} Revised estimate issued in December (see fn. 57, p. 34).

Source: Storage reports of the International Apple Association (issued November 15 and December 14, 1966).

Cooperative Extension Work: United States Department of Agriculture
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